Assessing Climate Change Vulnerabilities Across Lockheed Martin United States Facilities and Selected Segments of the C-130 Supply Chain

by

Saurabh Aneja
Amy Havens
Marisa Hobbs
Johannah Ramer

Dr. Jay Golden, Advisor

April 2016

Master’s Project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment, Duke University
Prepared For:
Lockheed Martin Corporation
6801 Rockledge Drive
Bethesda, MD 20817

Margaret Proul, Environmental Sustainability Program
Maribeth Malloy, Director for Strategic Engagement
Norman Varney, Associate General Counsel, Environmental, Safety, and Health
Philip Santiago, Senior Program Manager at Association of Climate Change Officers

Prepared By:
Nicholas School of the Environment
Duke University
450 Research Drive
Durham, NC 27708

Saurabh Aneja, MEM ‘16 – Energy and Environment
Amy Havens, MEM ‘16 – Energy and Environment
Marisa Hobbs, MEM’16 – Environmental Economics and Policy
Johannah Ramer, MEM’16 – Global Environmental Change

Project Advisor
Dr. Jay Golden, Director of Duke Center for Sustainability and Commerce

Acknowledgements
The Duke team would like to acknowledge Dr. Jay Golden, Margaret Proul, Maribeth Malloy, Norman Varney, the Lockheed Martin Corporation supply chain team in Marietta, Georgia and Philip Santiago from the Association of Climate Change Officers for their guidance, support, and input.
EXECUTIVE SUMMARY

The following report and accompanying tool were prepared for Lockheed Martin Corporation (LMC) by a team of Duke University Master of Environmental Management (MEM) students. The objective of this project was to assess the climate change vulnerabilities of the company’s major facilities in the United States, as well as its Tier 1 and Tier 2 suppliers for one component of the C-130 military transport aircraft program. The project sought to provide LMC with a practical and user-friendly instrument designed for decision-makers, and specifically serves to achieve the following:

1) Identify climate change-related regional risk factors
2) Determine potential disruption vulnerabilities in existing facilities and supply chains
3) Prioritize potential vulnerabilities and resulting investment targets
4) Recommend adaptation strategies
5) Provide vulnerability criteria to consider when establishing operations at new facilities and selecting suppliers.

In addition to the completion of requisite research and the report documenting our findings, we developed a Microsoft Excel vulnerability assessment tool using Visual Basic structuring. The tool provides vulnerability scores for six climate-change related risks across nine regions in the United States, and utilizes various time-scenarios. The six risks we selected include: 1) Drought, 2) Flooding, 3) Sea Level Rise, 4) Temperature, 5) Water Stress, and 6) Wildfire. We determined the risk levels in each region using historical data drawn from government agencies and projection data drawn from existing studies and models. Table E-1 summarizes the key risks identified in each region, along with facility, supplier, and employee counts at the LMC locations and supplier locations selected for this research project.

<table>
<thead>
<tr>
<th>Region</th>
<th>High &amp; Extreme Risks</th>
<th>Number of Major Facilities</th>
<th>Number of Employees at the Major Facilities</th>
<th>Number of Tier 1 Suppliers</th>
<th>Number of Tier 2 Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>Flood (C)</td>
<td>3</td>
<td>15,378</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Water Stress (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast</td>
<td>Flood (C)</td>
<td>6</td>
<td>11,183</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>Flood (C)</td>
<td>6</td>
<td>8,660</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Water Stress (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>Water Stress (S)</td>
<td>2</td>
<td>7,398</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southwest</td>
<td>Water Stress (C&amp;S)</td>
<td>1</td>
<td>4,157</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table E-1: Summary of Key Risks and Facility and Supplier Counts by Region
### Table E-1: Summary of Key Risks and Facility and Supplier Counts by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>High &amp; Extreme Risks</th>
<th>Number of Major Facilities</th>
<th>Number of Employees at the Major Facilities</th>
<th>Number of Tier 1 Suppliers</th>
<th>Number of Tier 2 Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Stress (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Northwest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Upper Midwest</td>
<td>Flood (C)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ohio Valley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Rockies &amp; Plains</td>
<td>Water Stress (C&amp;S)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** This table includes only the LMC facilities and supplier locations evaluated in this report.

Our research indicates that in the short-term (between now and 2040), water stress and flooding are the most significant potential risks for LMC. Sea level rise and wildfire risks may pose threats to operations as well, but these potential risks are only significant in the long-term, which we define as 2041 and beyond. It is therefore recommended that LMC focuses resiliency efforts on addressing flooding and water stress risks. One or both of these potential risks appear in each region where LMC has a significant number of facilities, employees, and suppliers. Of these two potential risks, we recommend LMC places more emphasis on addressing flooding, since LMC has already made notable progress in water conservation. Through the company’s “Go Green” initiatives, LMC has committed to reducing water use 30% by 2020. LMC has also paid extra attention to facilities located in particularly water-stressed areas: for example, in 2015, LMC determined water balances at three of its largest facilities in California to identify further opportunities for water conservation and water re-use at these sites.

We understand that LMC’s facility managers are addressing the current weather-related risks facing their facilities, such as flooding and drought. As a next step, we recommend that LMC complete a more localized assessment of potential short-term and long-term climate change-related risks at its facilities and supplier locations. Because we assessed risks at the regional level, our vulnerability scores mask potentially significant variation in vulnerability within a given region. For instance, across a region, flood risk will vary notably depending on elevation, proximity to rivers and coasts, and quality of infrastructure. As a result, although we calculated only one vulnerability score for flooding per region, locations within each region are likely to have highly variable exposure to flooding. Due to this limitation, we suggest performing a deeper dive into the specific risks at facilities and key supplier locations in one chosen region. Since our research found water stress and flooding to be two of the most prominent concerns in the near-term, this project team may want to focus its deeper analysis on assessing those particular risks. Finally, we also recommend that LMC continue to pay particular attention to the LMC facilities and supplier locations in the West region, since the West has the greatest number of high or extreme risks, especially over the long-term.
In addition to the drawback of assessing risk at the regional level, our project has several other limitations. First, there are limits to our assessment of current and future risk levels due to data availability. Our current vulnerability scores were based on assumptions drawn from historical data; however, weather often varies significantly across time, and, as a result, looking at data from the past may not provide a valid representation of current risk levels. Meanwhile, future vulnerability scores were derived from existing studies. The validity of this data, therefore, depends on the accuracy of the climate models upon which these studies are based. For both current and future vulnerability scores, the use of a 1-5 value to indicate regional vulnerability is another limitation, since others may have applied a different scoring system that could lead to new conclusions. Finally, for some risks, we were unable to find data across all three time periods (current, short-term, and long-term).

Despite these limits, the results of this research and associated vulnerability assessment tool provide LMC with the preliminary information needed to assess potential risk and develop adaptation plans to reduce climate change-related vulnerabilities across its facilities and supplier locations. As stated above, we believe LMC can build upon our preliminary assessment through the following:

1) Focus resiliency efforts on addressing potential flood and water stress risks in the short-term in regions where these risks have been identified;
2) Perform a deeper dive into the local risks at each facility and supplier location; and
3) Pay close attention to LMC and supplier operations in the West region due to the greatest number of high or extreme risks, especially in the long-term.

As climate change-related impacts increase the chance of disruption to normal business operations, it is important for LMC to take the steps needed to reduce its vulnerability.
# TABLE OF CONTENTS

Executive Summary ................................................................................................................. 3

Table of Contents .................................................................................................................. 6

1 Introduction ......................................................................................................................... 10

2 Lockheed Martin .................................................................................................................. 11
   2.1 Company Overview ......................................................................................................... 11
   2.2 C-130 Program ................................................................................................................. 11

3 Project Scope ......................................................................................................................... 12
   3.1 Project Team ...................................................................................................................... 12
   3.2 Initial Project Scope ......................................................................................................... 13
   3.3 Final Project Scope .......................................................................................................... 13

4 Literature Review ................................................................................................................. 14

5 Data Collection and Analysis ............................................................................................... 18
   5.1 Data Collection ................................................................................................................ 18
   5.2 NOAA Climate Regions ................................................................................................. 19
   5.3 Representative Concentration Pathways ....................................................................... 19
   5.4 Assessment of Environmental Risks .............................................................................. 20

6 Interactive Vulnerability Assessment Tool ........................................................................... 39
   6.1 Overview of the Vulnerability Assessment Tool ............................................................... 39
   6.2 Use of the Vulnerability Assessment Tool ..................................................................... 39
   6.3 Parameters of the Tool ................................................................................................... 39
   6.4 Outputs of the Tool ......................................................................................................... 41

7 Research Findings ............................................................................................................... 42
   7.1 Climate Change-Related Risks Affecting Each Climate Region ...................................... 42

8 Discussion and Recommendations ....................................................................................... 54
   8.1 Adaptation Strategies ..................................................................................................... 56
   8.2 Facility Adaptation ......................................................................................................... 57
   8.3 Supplier Adaptation ....................................................................................................... 59
   8.4 Summary ......................................................................................................................... 60

9 Project Limitations ............................................................................................................... 60

10 Further Research to Be Done .............................................................................................. 61

11 Conclusions ......................................................................................................................... 62

12 Glossary ............................................................................................................................... 64

13 References .......................................................................................................................... 66

14 Appendices .......................................................................................................................... 87
LIST OF FIGURES

Figure 2-1: The C-130J Super Hercules ........................................................................................................... 12
Figure 3-1: LMC Facilities and Tier 1 and 2 Suppliers Assessed for the Project ........................................ 14
Figure 4-1: Perceived Likelihood and Impact of Global Risks per the 2014 Global Risks Perceptions Survey .......................................................................................................................... 14
Figure 4-2: Perceived Likelihood and Impact of Global Risks with Ranks 1-7 per the Global Risks Perceptions Survey .................................................................................................................. 15
Figure 4-3: Six Main Risks Climate Change Presents to Businesses. Adapted from McKinsey & Company (2015) ........................................................................................................................................ 16
Figure 5-1: NOAA Climate Regions .............................................................................................................. 19
Figure 5-2: IPCC Representative Concentration Pathways ............................................................................ 20
Figure 5-3: Frequency of Floods Across the United States (1985-2011) ...................................................... 24
Figure 5-4: Flood Risk Across the United States (2000-2009) ..................................................................... 24
Figure 5-5: Projected Global Sea Surface Temperature Change ................................................................. 25
Figure 5-6: Projected Global Sea Level Rise through 2100 ......................................................................... 26
Figure 5-7: Snow Cover Percent Change in the Northern Hemisphere (1986-2100) ................................. 28
Figure 5-8: Change in Total Snowfall in the Contiguous 48 States, 1930-2007 ............................................ 29
Figure 5-9: Predicted Temperature Increases Under Multiple Emissions Scenarios .................................... 30
Figure 5-10: Predicted Changes in Surface Temperature by the End of the 21st Century .......................... 30
Figure 5-11: Atlantic Basin Storm Count ...................................................................................................... 33
Figure 5-12: Average Annual Area Burned and Number of Fires per Year in the United States .............. 36
Figure 5-13: Wildfire Losses in the United States, 2005-2014 (adjusted for inflation) ............................... 37
Figure 5-14: Range of Very Large Fire Weeks Expected ................................................................................ 38
Figure 6-1: Visualization of the Tool’s UserForm Object Prior to Run ....................................................... 39
Figure 6-2: Sample Screenshot of Output from the Tool .............................................................................. 40
Figure 6-3: Sample Screenshot of Geographical Heat Map .......................................................................... 41
Figure 8-1: Process to Determine Response to a Climate Change-Related Risk .......................................... 56
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-1</td>
<td>Summary of Key Risks and Facility and Supplier Counts by Region</td>
</tr>
<tr>
<td>5-1</td>
<td>Risks Assessed and Corresponding Data Sources</td>
</tr>
<tr>
<td>5-2</td>
<td>Vulnerability Scores and Risk Levels</td>
</tr>
<tr>
<td>5-3</td>
<td>Explanation of Palmer Drought Severity Index and Vulnerability Scores</td>
</tr>
<tr>
<td>5-4</td>
<td>Explanation of Drought Risk Index Using WRI Data</td>
</tr>
<tr>
<td>5-5</td>
<td>Explanation of Flood Risk Index Using WRI Data</td>
</tr>
<tr>
<td>5-6</td>
<td>Sea Level Rise Time Frames and Associated Vulnerability Scores</td>
</tr>
<tr>
<td>5-7</td>
<td>Explanation of Vulnerability Scores for Temperature</td>
</tr>
<tr>
<td>5-8</td>
<td>Explanation of Vulnerability Scores for Current Water Stress</td>
</tr>
<tr>
<td>5-9</td>
<td>Description of Vulnerability Scores for Short-Term Water Stress</td>
</tr>
<tr>
<td>5-10</td>
<td>VLF Ranges and Corresponding Vulnerability Scores</td>
</tr>
<tr>
<td>7-1</td>
<td>Summary of Risks for the Northwest Region</td>
</tr>
<tr>
<td>7-2</td>
<td>Summary of Risks for the West Region</td>
</tr>
<tr>
<td>7-3</td>
<td>Summary of Risks for the Southwest Region</td>
</tr>
<tr>
<td>7-4</td>
<td>Summary of Risks for the Northern Rockies and Plains Region</td>
</tr>
<tr>
<td>7-5</td>
<td>Summary of Risks for the Upper Midwest Region</td>
</tr>
<tr>
<td>7-6</td>
<td>Summary of Risks for the Central (Ohio Valley) Region</td>
</tr>
<tr>
<td>7-7</td>
<td>Summary of Risks for the Southeast Region</td>
</tr>
<tr>
<td>7-8</td>
<td>Summary of Risks for the South Region</td>
</tr>
<tr>
<td>7-9</td>
<td>Summary of Risks for the Northeast Region</td>
</tr>
<tr>
<td>8-1</td>
<td>Summary of Key Risks and Facility and Supplier Counts by Region</td>
</tr>
</tbody>
</table>
LIST OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCO</td>
<td>Association of Climate Change Officers</td>
</tr>
<tr>
<td>C2ES</td>
<td>Center for Climate and Energy Solutions</td>
</tr>
<tr>
<td>CDP</td>
<td>Carbon Disclosure Project</td>
</tr>
<tr>
<td>CMIP5</td>
<td>Coupled Model Intercomparison Project Phase 5</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>GACC</td>
<td>Geographic Area Coordination Center</td>
</tr>
<tr>
<td>GCM</td>
<td>Global Circulation Model</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>LEED</td>
<td>Leadership in Energy and Environmental Design</td>
</tr>
<tr>
<td>LMC</td>
<td>Lockheed Martin Corporation</td>
</tr>
<tr>
<td>MEM</td>
<td>Master of Environmental Management</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NRDC</td>
<td>Natural Resources Defense Council</td>
</tr>
<tr>
<td>QDR</td>
<td>Quadrennial Defense Review</td>
</tr>
<tr>
<td>RCP</td>
<td>Representative Concentration Pathway</td>
</tr>
<tr>
<td>SSCM</td>
<td>Sustainable Supply Chain Management</td>
</tr>
<tr>
<td>VLF</td>
<td>Very large fire</td>
</tr>
<tr>
<td>WBCSD</td>
<td>World Business Council for Sustainable Development</td>
</tr>
<tr>
<td>WRI</td>
<td>World Resources Institute</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

Climate change is the process in which an area’s typical climate, including its temperature and precipitation patterns, varies over time. Many natural factors contribute to climate change, such as alterations in the earth’s orbit, changes in sunlight intensity, and natural fluctuations in greenhouse gas (GHG) concentrations. However, since the mid-1900s, humans have become a significant contributor to climate change by engaging in activities that result in the release of high quantities of GHG emissions, such as carbon dioxide, into the atmosphere. Because these gases absorb sunlight that is reflected off earth’s surface, elevated GHG concentrations are raising earth’s temperature. This situation has resulted in troubling predictions about the earth’s future climate. In the United States, predicted changes in climate vary by location, but general trends include rising temperatures, heavier precipitation, more severe droughts and heat waves, and increased flooding from sea level rise.

Environmental conditions can impact a business’s profits and reputation, since weather- and climate-related factors can lead to facility disruptions, higher operating costs, diminished worker productivity, and failed on-time delivery. For example, Entergy, a leading energy company in the Southern United States, lost $2 billion as a result of damaged infrastructure due to Hurricane Katrina and Hurricane Rita. Across California, domestic and commercial customers have collectively seen energy bills increase that same amount ($2 billion) over four years as the drought has reduced hydroelectric power generation. For companies with international operations, there have also been costly weather- and climate-related impacts. In 2011, floods in Thailand led many computer manufacturers to see significant declines in revenue after their factories were damaged.

Preparing for climate change-related risks has also grown increasingly important to Lockheed Martin Corporation (LMC)’s largest customer: the U.S. Department of Defense (DoD). The DoD’s 2014 Quadrennial Defense Review (QDR) listed climate change as a “significant challenge” for the United States and the world. With environmental conditions expected to worsen in the face of climate change, it is important for LMC to prepare to address these conditions and thereby avoid the potential for consequential interference with its customer obligations. The company has already taken several proactive steps, including reducing energy and water use, developing clean energy technology, and improving supply chain sustainability. In order to advance its business practices in a more sustainable manner, LMC understands the need to identify climate change-related risks that could potentially disrupt its facilities and supply chain.

Our project aims to provide a practical tool that identifies these risks and points to opportunities for increasing the company’s resiliency. More specifically, we aim to provide a tool that can aid LMC with the following:

1) Identify climate change-related regional risk factors
2) Determine potential disruption vulnerabilities in existing facilities and supply chains
3) Prioritize potential vulnerabilities and resulting investment targets
4) Recommend adaptation strategies
5) Provide vulnerability criteria to consider when establishing operations at new facilities and selecting suppliers
To achieve this goal, we developed an Excel-based tool that provides vulnerability scores for nine regions across the United States where selected LMC facilities and suppliers are located. We evaluated both Tier 1 and Tier 2 supplier locations; Tier 1 suppliers deliver parts directly to LMC, and Tier 2 suppliers are key suppliers to those Tier 1 suppliers. This report summarizes the process used to develop these scores and create the tool, as well as highlights steps LMC could take to reduce its potential climate change-related vulnerabilities as identified based on the tool’s results.

2 LOCKHEED MARTIN

2.1 Company Overview

Lockheed Martin Corporation is a global aerospace and defense company headquartered in Bethesda, Maryland. The company was formed in 1995 as a merger of Lockheed Corporation with Martin Marietta Corporation, both founded in 1912. LMC designs and manufactures advanced technology systems, products, and services in five business segments: Aeronautics, Information Systems and Global Solutions, Missiles and Fire Control, Mission Systems and Training, and Space Systems. In 2015, 78% of LMC’s $46.1 billion in net sales were from the U.S. Government (with 58% of these sales from the DoD), 21% were from international customers, and 1% were from U.S. commercial and other customers.

As of December 31, 2015, LMC employed approximately 126,000 people, 93% of whom are located in the United States. The company leases or owns approximately 590 facilities, primarily in the United States, as well as in Australia, Canada, Germany, Greece, Israel, United Kingdom, Saudi Arabia, the United Arab Emirates, and other countries.

LMC has a strong commitment to sustainability and proactively manages, measures, and discloses sustainability performance. Sustainability performance at LMC is separated into six priority areas: Governance, Product Performance, Talent Competitiveness, Supplier Sustainability, Resource Efficiency, and Information Security. Since 2011, LMC has released an annual corporate sustainability report outlining its commitments and progress. The company also reports to the Carbon Disclosure Project (CDP) on its efforts to address climate change and water use. Our aim is to build upon LMC’s existing efforts by highlighting opportunities to reduce the potential for climate change-related impacts at LMC’s facilities and supplier locations.

2.2 C-130 Program

To help build the tool using real-world data, LMC’s C-130 program was selected as a test case for the supply chain portion of this research. The C-130 is a military transport aircraft designed and developed by Lockheed Martin. Since the original C-130A was developed in 1954, over 1.2 million flight hours have been logged worldwide. The aircraft is used for various types of missions, including personnel transport, special operations, search and rescue, humanitarian
relief, and others (Figure 2-1). A C-130J aircraft, the current model, is capable of transporting more than 40,000 pounds of cargo and supplies. Currently, 16 countries operate the C-130J.

**Figure 2-1:** The C-130J Super Hercules

### 3 PROJECT SCOPE

#### 3.1 Project Team

This project is a collaboration between Duke University, the Lockheed Martin Corporation, and the Association of Climate Change Officers (ACCO). The team members are shown below.

**Duke University**
- Saurabh Aneja, MEM – Energy and Environment
- Amy Havens, MEM – Energy and Environment
- Marisa Hobbs, MEM – Environmental Economics and Policy
- Johannah Ramer, MEM – Global Environmental Change
- **Advisor:** Dr. Jay Golden, Director of Duke Center for Sustainability and Commerce

**Lockheed Martin Corporation**
- Margaret Proul, Environmental Sustainability Program Manager
- Maribeth Malloy, Director for Strategic Engagements
- Norman Varney, Associate General Counsel, Energy, Environment, Safety, and Health
- Sam Baker, Climate Change and Renewable Energy Specialist

**Association of Climate Change Officers**
- Philip Santiago, Senior Program Manager
3.2 Initial Project Scope

The Duke team was formed in March 2015 as student consultants to LMC to analyze the climate change resiliency of LMC facilities and Tier 1 suppliers. The initial project objective posed to the Duke team was as follows:

“Lockheed Martin seeks to gain additional perspective on the resiliency of its facilities and Tier 1 suppliers to climate change impacts. The objectives of this project are to assess the climate change vulnerabilities of major Lockheed Martin facilities, and the Tier 1 suppliers. Students will determine the most vulnerable areas of Lockheed Martin’s operations and/or supply chain and will identify priority focus areas to decrease vulnerability.”

Through our initial conversations with LMC, it was determined that the project scope would be modified to analyze potential climate change risks related to 30 LMC facilities, both in the United States and in other countries, as well as to a sub-set of Tier 1 and Tier 2 suppliers. Tier 1 suppliers are suppliers that LMC has a direct contractual relationship with, and Tier 2 suppliers are Tier 1 suppliers’ first-tier suppliers. We initially defined the climate change risks we would analyze as regulatory, environmental, geologic, energy, social, financial, resiliency, transportation, and political (Appendix A). The original scope also included a facility-level, rather than regional-level, analysis of risks.

3.3 Final Project Scope

Over the length of the project, from March 2015 through April 2016, both LMC and the Duke team realized that due to the significant breadth of the original scope, the original scope could not reasonably be completed in one year. As a result, the project reduced the number of initial risks to include only climate change-related environmental risks (see Section 5 - Data Collection and Analysis). In addition, the team narrowed down the locations of facilities and suppliers to limit them to those located in the United States. For this project, the Duke team looked at a total of 18 facilities, 14 Tier 1 supplier locations, and 5 Tier 2 supplier locations, as shown in Figure 3-1. The facilities were selected by LMC due to their size and/or relative significance to the company’s operations. The suppliers were selected due to their relationship to the C-130 Program. Lastly, at the request of LMC, the Duke team analyzed the environmental risks on a regional level, rather than at the facility level so that LMC could use this tool to assess multiple LMC site locations and supplier locations. Our final deliverables for the project include this report and an Excel-based tool (see Section 6 – Interactive Vulnerability Assessment Tool).
4 LITERATURE REVIEW

There is a growing awareness of the threat environmental risks, including climate change, bring to society, the economy, and businesses. Results from the World Economic Forum’s 2014 Global Risks Perception Survey indicate that environment-related factors—such as water crises, extreme weather events, natural catastrophes, and failure to adapt to climate change—are some of the most likely global risks.\(^{26}\) Furthermore, both water scarcity and lack of climate change adaptation efforts by government and businesses were perceived as being within the top five global risks when ranked by severity of impacts.\(^ {27}\) Figures 4-1 and 4-2 below display these findings.

**Figure 4-1: Perceived Likelihood and Impact of Global Risks per the 2014 Global Risks Perceptions Survey\(^ {28}\)**
These environment- and climate change-related risks can have a harmful impact on the bottom line of a company. McKinsey & Company has identified six major risks of climate change to a business. The first three are risks to a company’s value chain: these risks include 1) physical risks, such as damage to infrastructure and assets, 2) price risks due to increasingly volatile raw material costs, and 3) product risks as both consumer sentiment on sustainability and new regulations affect demand. The second three risks relate to external-stakeholder relations. These include: 4) credit ratings risks that arise from negative value-chain impacts, such as disruptions to supply chains, 5) regulation risk from new environmental laws, and 6) reputation risk as customers come to demand higher levels of sustainability from businesses. Figure 4-3 summarizes these risks. Our project focuses on the potential physical risks climate change poses to LMC.
With regard to physical risk, extreme weather can damage infrastructure, interrupt production schedules, and interfere with delivery—all of which can negatively affect a company’s financial performance and reputation. The risk of disturbances across a supply chain, in particular, have increased as supply chains have grown leaner and expanded internationally. A 2012 Supply Chain Risk Radar Survey from the World Economic Forum found that natural disasters and extreme weather were the top two causes of supply chain disruption. In some cases, the financial repercussions of these disruptions were extreme: a 2005-2011 study by Accenture found that stock values declined by an average of 7% following the public announcement of a company’s supply chain disruptions.

As awareness of these risks has grown, so too has demand for companies to address these risks. Investors have begun to expect companies to disclose climate-change related risks and work to reduce them. Furthermore, in 2010, the Securities and Exchange Commission released a new guidance document requiring companies to disclose climate change-related risks that could significantly affect their profits, including weather-related disruptions to manufacturing facilities or supply chains.

Several companies have begun taking steps to identify and reduce these climate-related risks. Nike, whose heavy use of cotton made the company vulnerable to drought and water stress, is now using more synthetic materials that are less vulnerable to these impacts. The company has also adopted a new carbon-based dyeing process that requires no water, and thus further reduces the company’s vulnerability to water-related risks. As another example, Entergy has focused on assessing physical risks to its infrastructure and operations. Following multiple hurricanes in 2005, the company completed a study to assess near-term, medium-term, and long-term climate-related risks to its infrastructure and service areas and identify ways to reduce these risks. In some instances, the company has even relocated infrastructure to regions less susceptible to risks, especially flooding.
The DoD, LMC’s largest customer, has also begun to focus on climate change preparedness. In 2010, the DoD released a Strategic Sustainability Performance Plan that describes the department’s decade-long plan for mitigating and adapting to climate change. In 2014, the DoD released the Quadrennial Defense Review (QDR) outlining the three pillars of the U.S. defense strategy. The QDR lists climate change as a “significant challenge” for the United States and the world, with the potential to exacerbate poverty, environmental degradation, and political instability. Furthermore, the report stated that climate change could affect missions and U.S. operations; therefore, the DoD is committed to assessing potential climate change impacts and developing plans to adapt.

The DoD also released a Climate Change Adaptation Roadmap in 2014 focused exclusively on how the department can adapt to risks such as rising temperatures, heavier precipitation, more extreme weather, and rising sea levels. One goal outlined in this Roadmap is to ensure that DoD suppliers are addressing sustainability. This goal can be a motivating factor for defense contractors like LMC to advance their climate change preparedness. In January 2016, the DoD released a new directive further committing the department to reducing climate change risks that could affect its mission, such as potential impacts to infrastructure, critical suppliers, and transportation routes.

Several of the DoD’s efforts to enhance its climate change preparedness were reviewed by the Duke team in order to assess their applicability to LMC. As an example, DoD’s Climate Change Adaptation Roadmap outlines a commitment to reducing the vulnerability of defense infrastructure to climate change-related risks, with possible risks including damage from floods, thawing permafrost, water and energy shortages, and higher costs for heating and cooling needs. To achieve this goal, the DoD has undertaken vulnerability assessments of its infrastructure and is starting to assess climate change vulnerability when investing in new infrastructure.

Through these examples, it is evident that there is a growing trend across the public and private sectors to assess and reduce climate change vulnerability. Businesses and government agencies, including the DoD, are becoming more aware of the economic and societal risks that extreme weather, rising temperatures, and reduced resource availability present. Our goal through this project is to provide a tool that will help LMC in its continued efforts to identify existing data gaps and to develop adaptation plans to reduce vulnerability to these potential risks.
5 DATA COLLECTION AND ANALYSIS

5.1 Data Collection

The data collection process for this project took place between August 2015 and December 2015. We collected over 200 reports, academic papers, and datasets covering current and projected climate change risks, impacts, and adaptation measures. A snapshot of the data sources collected is shown in Appendix B.

Increased storm intensity, rising temperatures, wildfires, drought, health impacts, sea level rise, ocean acidity, flooding, melting glaciers, and biodiversity loss are identified as some of the most significant threats of climate change.\textsuperscript{55,56,57} We ultimately chose to assess nine climate-change related risks, six of which we included in our vulnerability assessment tool, as shown in Table 5-1, below. The data we selected for the tool aligned with one or more of the time frames in the tool: current, short-term (2020-2040), and long-term (2041-2070).

<table>
<thead>
<tr>
<th>Risk</th>
<th>Data Source</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Palmer Drought Severity Index\textsuperscript{58}</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>WRI Aqueduct Water Risk Atlas\textsuperscript{59}</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>WRI Aqueduct Water Risk Atlas\textsuperscript{60}</td>
<td>Current</td>
</tr>
<tr>
<td>Ocean Temperature</td>
<td>IPCC\textsuperscript{61}</td>
<td>NA</td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>Climate Central Surging Seas Database\textsuperscript{62}</td>
<td>Long-Term</td>
</tr>
<tr>
<td>Snow</td>
<td>EPA Climate Change Indicators\textsuperscript{63}</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>IPCC</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>The American Climate Prospectus,</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>Climate Prospectus Team\textsuperscript{64}</td>
<td>Short-Term Long-Term</td>
</tr>
<tr>
<td>Tropical Cyclones</td>
<td>EPA Climate Change Indicators\textsuperscript{65}</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>NOAA\textsuperscript{66}</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>WRI Aqueduct Water Risk Atlas\textsuperscript{67}</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short-Term</td>
</tr>
<tr>
<td>Wildfires</td>
<td>Barbero et al. (2015)\textsuperscript{68}</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long-Term</td>
</tr>
</tbody>
</table>

\textbf{Bold} = Included in the Duke-LMC Vulnerability Assessment Tool

For each risk assessed in the model, we translated the data into a vulnerability score of 1-5 for each region and each timeframe where data was available. The vulnerability scores were developed in one of two ways: (1) built directly from indices present in the datasets themselves, or (2) adapted from ranges in the datasets and modified to fit our tool. Each score corresponds to a risk level from low risk to extreme risk, as shown in Table 5-2, below.
Table 5-2: Vulnerability Scores and Risk Levels

<table>
<thead>
<tr>
<th>Vulnerability Score</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low Risk</td>
</tr>
<tr>
<td>2</td>
<td>Low to Moderate Risk</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Risk</td>
</tr>
<tr>
<td>4</td>
<td>High Risk</td>
</tr>
<tr>
<td>5</td>
<td>Extreme Risk</td>
</tr>
</tbody>
</table>

5.2 NOAA Climate Regions

National Oceanic and Atmospheric Administration (NOAA) scientists identified nine climate regions in the contiguous United States using data developed by Karl & Kloss, 1984. For our vulnerability assessment tool, we used the same nine regions.

Figure 5-1: NOAA Climate Regions

5.3 Representative Concentration Pathways

The Intergovernmental Panel on Climate Change (IPCC), the prominent organization for climate change assessment, developed a set of Representative Concentration Pathways (RCPs) used for projecting GHG emissions based on seven key factors: population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy. Four RCPs scenarios are proposed (Figure 5-2): the low emissions scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one high emissions scenario (RCP8.5). “Business as Usual”, or a scenario without any efforts to reduce emissions, falls between RCP6.0 and RCP8.5. In our risk tool, we used projection data assuming scenario RCP8.5.
5.4 Assessment of Environmental Risks

For each environmental risk assessed, the section below includes a description of the data collected, the analytical process we applied, and the limitations of our analysis.

5.4.1 Drought

Overview of Risk
A drought is a prolonged period of reduced precipitation that leads to water shortages.\(^{74}\) Although droughts occur naturally, predictions are that drought severity will worsen over time as climate changes—especially in certain areas of the country.

A review of relevant studies points to worsening drought in the Western United States. Seager et al. (2007) applied 19 climate models utilized in the IPCC Fourth Assessment Report to assess aridity changes, and found that aridity in the Southwest United States will increase over the 21st century.\(^{75}\) Cook et al. (2004) drew similar conclusion after using tree ring records dating 1,200 years back to explore historical patterns in droughts.\(^{76}\) The authors found atypical increases in aridity in the Western United States since the start of the 21st century, and believe increasing temperatures could promote extreme droughts in the future.\(^{77}\) More recently, Cook et al. (2015) used 17 Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) to explore patterns in precipitation, evapotranspiration, and soil moisture over the next century and compared these results to historical records.\(^{78}\) The authors conclude that in the 21st century, the Southwest and Central Plains will become drier thanks to higher evaporation rates, the region will face increased risk of decadal or multi-decadal droughts, and drought intensity will likely be worse than that of the severe droughts that took place during the Medieval era.\(^{79}\) Drought risks will also be magnified by the fact that increasing water consumption and decreasing freshwater supplies are already straining water resources.\(^{80}\)

Some of the risk drought poses to businesses has been demonstrated through the recent occurrences in California. The state has been in a drought since 2011, as a result of both natural climate variability and anthropogenic climate change.\(^{81}\) Climate change has increased
temperatures and led to faster evaporation of water, as well as reduced mountain snowpack that serves as a critical water source in the area. In response to the drought, California enacted its first mandatory water use reduction legislation in 2015, Executive Order B-29-15, after declaring a State of Emergency over persistent drought conditions in the region. Under this legislation, water supply agencies have been required to reduce water use by 25% and commercial properties have been directed to become more water efficient. These types of restrictions could pose concerns to businesses whose production processes are heavily water dependent.

LMC is already experiencing drought impacts at some of their facilities in the United States. At LMC’s Sunnyvale, California facility, high temperatures and drought have increased cooling demand at the facility and increased stress on the city water supply. Utility water rates have increased by 5% each year from 2013 to 2015, and they are expected to increase in the coming years. Furthermore, the currently imposed 25% water use restriction at LMC’s California facilities has the potential to affect production at those facilities. Similarly, several of LMC’s Texas facilities are located in drought-prone regions, and thus if those facilities were to face water use restrictions in the near future, production at those facilities could be affected as well.

Data Analysis
To assess current drought risk, we first analyzed Palmer Drought Severity Index scores. The Palmer Drought Severity Index indicates the dryness in a region based on temperature and precipitation data: the driest regions have scores of -10, while the wettest have scores of 10. Table 5-3, below, explains the range of the Palmer Drought Severity Index. Using the NOAA National Centers for Environmental Information, we obtained the annual Palmer Drought Severity Index scores for the 15-year period from 2000 to 2014. To translate these values into vulnerability scores of 1-5, we aligned them with the existing Palmer Drought Severity Index system, as is also shown in Table 5-3.

<table>
<thead>
<tr>
<th>Palmer Drought Severity Index Score</th>
<th>Meaning</th>
<th>Our Vulnerability Score</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.0 or less</td>
<td>Extreme Drought</td>
<td>5</td>
<td>Extreme</td>
</tr>
<tr>
<td>-3.0 to -3.9</td>
<td>Severe Drought</td>
<td>4</td>
<td>High</td>
</tr>
<tr>
<td>-2.0 to -2.9</td>
<td>Moderate Drought</td>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>-1.9 to +1.9</td>
<td>Near Normal</td>
<td>2</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td>+2.0 to +2.9</td>
<td>Unusual Moist Spell</td>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>+3.0 to +3.9</td>
<td>Very Moist Spell</td>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>+4.0 and above</td>
<td>Extremely Moist</td>
<td>1</td>
<td>Low</td>
</tr>
</tbody>
</table>

Since the past 15 years are not necessarily indicative of drought risk in a particular region in the United States, we used the World Resource Institute (WRI)’s Aqueduct Water Risk Atlas for additional insight. The tool indicates historic drought severity from 1901 to 2008 in each catchment (defined as an area in which all water drains to the same location); drought severity is a function of drought duration (number of months) and intensity (extent of decrease in soil moisture). WRI obtained this data from a study by Sheffield and Wood (2008). Since the WRI data came in Geographic Information Systems (GIS) shapefiles, we intersected these shapefiles with the nine climate regions and then found the average drought risk across each region. Since WRI already normalized their drought severity values to be between 0 and 5, we
adopted WRI’s existing index to create our vulnerability scores of 1-5, as shown in Table 5-4, below.

<table>
<thead>
<tr>
<th>WRI Index System</th>
<th>Our Vulnerability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drought Severity Value</strong></td>
<td><strong>Meaning</strong></td>
</tr>
<tr>
<td>0-1</td>
<td>Low (&lt;20)</td>
</tr>
<tr>
<td>1-2</td>
<td>Low to Medium (20-30)</td>
</tr>
<tr>
<td>2-3</td>
<td>Medium to High (30-40)</td>
</tr>
<tr>
<td>3-4</td>
<td>High (40 to 50)</td>
</tr>
<tr>
<td>4-5</td>
<td>Extremely high (&gt;50)</td>
</tr>
</tbody>
</table>

We found that both the Palmer Drought Severity Index scores from 2000 to 2014 that we collected and the WRI data result in the same overall drought risk scores for all regions, except for the Northern Rockies. In that case, we chose to use the risk score from the WRI dataset, since the data covers a larger time period.

**Limitations of Data**
The main concern about using this historical data is that current drought risk may vary significantly from the average across the last 15 years (in the case of the NOAA data) or previous century (in the case of the WRI data). The Palmer Drought Severity Index, in particular, often changes greatly from year to year. For example, in the region designated as the West, the Palmer Drought Severity Index was at 1.6 (near normal) in 2011, but then reached -3.3 (severe drought) in 2012. However, we believe that, overall, the data still shows the general tendency for a region in the United States to face drought.

As for predicting future drought, we did not find data that provided these projections for each region. NOAA’s Climate Prediction Center provides only short-term predictions (approximately 3-month outlooks) for drought across the country. However, we did find studies (as cited above) that predict worsening drought conditions across the West, Southwest, and Southern United States by 2100.

**5.4.2 Flood**

**Overview of Risk**
Flooding is another weather and climate-related risk that is predicted to worsen as the climate changes. The IPCC anticipates that heavier precipitation will lead to more flooding across certain regions of the world, and expects higher damage from river and coastal floods in urban areas across the United States. Extreme floods may also rise: Milly et al. (2002) created a climate model to assess anticipated changes in 100-yr floods across 29 basins and found that the frequency of these low-probability, high impact floods will likely increase as emissions rise.

Over the past several decades, total precipitation, heavy precipitation events, and flooding have already notably increased in the Northeast, Midwest, and Ohio River Valley. Although some
regions in the United States will see decreases in total precipitation in the 21st century, the frequency of extreme precipitation is expected to rise across the country. Heavy precipitation can cause rivers, streams, and lakes to overflow, as well as overwhelm wastewater infrastructure. Coastal flooding—which climate change will magnify through more intense storms and increasing sea levels—is also a concern: under RCP8.5, coastal storms are expected to cause $29 to $30.5 billion in annual damage to commercial and residential property and disruption to business activity by 2030.

**Data Analysis**

To assess current flood risk, we again utilized WRI’s Aqueduct Water Risk Tool. By intersecting the GIS shapefiles with the nine United States regions, we were able to obtain the data on past flood occurrence in each catchment. This data, which WRI obtained from the Global Flood Observatory, indicates the number of floods in a location between 1985 and 2011. This number includes inland, coastal, and flash floods. We took the average flood occurrence across all catchments in a region to find the current regional flood risks. Since WRI already normalized these flood risk values, we adopted their index to create vulnerability scores of 1-5, as presented in Table 5-5.

<table>
<thead>
<tr>
<th>Flood Occurrence Value</th>
<th>WRI Index System</th>
<th>Our Vulnerability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Low (0-1)</td>
<td>1 Low</td>
</tr>
<tr>
<td>1-2</td>
<td>Low to Medium (2-3)</td>
<td>2 Low to Moderate</td>
</tr>
<tr>
<td>2-3</td>
<td>Medium to High (4-9)</td>
<td>3 Moderate</td>
</tr>
<tr>
<td>3-4</td>
<td>High (10-27)</td>
<td>4 High</td>
</tr>
<tr>
<td>4-5</td>
<td>Extremely high (&gt;27)</td>
<td>5 Extreme</td>
</tr>
</tbody>
</table>

A study by the Natural Resources Defense Council (NRDC) largely echoes the results provided through the WRI Aqueduct Water Risk Tool. NRDC used USGS data to observe the frequency of days with recorded flood conditions during 2000-2009, as well as the frequency of days with extreme high streamflow compared to the baseline level across 1961-1990. Both the flood risk map resulting from the WRI tool (see Figure 5-3) and that resulting from the NRDC study (see Figure 5-4) point to a similar distribution of flood risk across the country.
**Figure 5-3:** Frequency of Floods Across the United States (1985-2011)

**Figure 5-4:** Flood Risk Across the United States (2000-2009)

**Limitations of Data**

The validity of our current flood vulnerability scores depends on how well past flood risks across the years 1985-2011 represent current flood risk. As for future flood risk, we did not find datasets that provide predictions of future flood occurrences in each region. However, as stated above, expectations are that flood frequency and severity could potentially increase in many regions in the face of heavier precipitation, coastal storms, and sea level rise. The severity of these floods will depend on additional factors too, such as the existence of dams or dykes that can hold back floods, the presence of permeable surfaces, and the population and building...
density in the affected area.\textsuperscript{108} A significant portion of infrastructure across the United States is already in need of upgrades, another factor that can add to flood vulnerability.\textsuperscript{109}

### 5.4.3 Ocean Temperatures

**Overview of Risk**

As the climate warms, the oceans absorb much of this excess heat from the atmosphere, thereby increasing the surface temperature of the ocean.\textsuperscript{110} Data from the IPCC and NOAA indicates that during the time period of 1901-2012, the global sea surface temperature rose by an average of 0.14°F per decade.\textsuperscript{111} Over the 111 year timeframe, the temperature rose between 1°F and 4°F depending on the region, with the largest temperature increases in the Southern Hemisphere, south and west of Africa.

Globally, sea surface temperatures are expected to increase during the first half of the 21\textsuperscript{st} century.\textsuperscript{112,113} Under all RCP scenarios, the projected average annual global sea surface temperature is expected to be warmer as compared with 1980-2005. Rising sea temperatures may increase the intensity of tropical cyclones and further influence sea level rise.\textsuperscript{114}

**Figure 5-5:** Projected Global Sea Surface Temperature Change\textsuperscript{115}

![Projected Global Sea Surface Temperature Change](image)

**Data Analysis**

We did not include ocean temperatures in our risk tool because rising ocean temperatures are not directly related to the risks faced at the LMC facilities or supplier locations evaluated for this project. However, we assessed the literature because of the critical role ocean temperature can play in sea level rise, tropical storm, and hurricane risk—all of which may pose a threat to LMC.
5.4.4 Sea Level Rise

Overview of Risk
Sea level rise is a risk that threatens coastal businesses and communities globally. Sea level rise is caused by a series of processes: the first is the expansion of water from increasing sea surface temperature, and the second is from melting land ice exacerbated by rising global air temperatures. Since 1880, sea level has been rising globally at an average rate of six-tenths of an inch per decade. Recently, however, sea level has been increasing by approximately one inch each decade. Per the IPCC Fifth Assessment, sea level is expected to rise anywhere from 1-3 feet by 2100. Oceans slowly respond to changing atmospheric temperature, on the scale of thousands of years, thus the sea level will continue to rise regardless of whether emissions slow down. The effects of sea level rise will vary on the local scale, but will have consistent impacts on storm surge and other short-term flooding events that will occur from increased precipitation and storm events.

Figure 5-6: Projected Global Sea Level Rise through 2100

Data Analysis
The data for this section was taken from the Surging Seas Database created by Climate Central. This database uses sea level rise projections from Kopp et. al (2014), combined with elevation data provided by NOAA and U.S. Geological Survey, United States tidal elevation data from NOAA, and levee information for Louisiana from the Army Corps of Engineers, to determine when the coastal areas of the United States will reach one foot of sea level rise (one foot above median high tide of 2012) at each of the tidal stations. The map then gave the most probable year, rounded to the nearest decade, when that location would reach one foot of sea level rise under the RCP8.5 climate scenario. One foot of sea level rise will have different repercussions depending on the location and conditions. Sea level rise has localized effects; at one foot of sea level rise, areas prone to storm surge and flooding will experience a more severe impact by 2050, specifically in the Southeast. By 2050, 100-year flooding events may have decadal or annual frequency in some locations along the coasts.

The vulnerability scores were calculated using an average of the data provided by the Climate Central Surging Seas Database. The data was compiled by taking the year that each tidal station would most likely reach one foot above median high tide (using a 2012 baseline) and finding the
The sea level rise data was then interpreted by looking at the averaged timeframe in which a region would reach one foot of sea level rise. Though one foot of sea level rise may be a minor problem, it is an indicator of how quickly sea level will rise in that region moving forward. The earliest average year a region is anticipated to reach one foot of sea level rise was taken as the starting year for the highest risk. Every subsequent 15-year time period, the average long-term timeframe for business planning, was assigned a vulnerability score in decreasing risk order. The compiled data is shown in Table 5-6, below.

<table>
<thead>
<tr>
<th>Average Number of Years to Reach 1 Foot of Sea Level Rise*</th>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 - 45 years (2042 – 2056)</td>
<td>5</td>
<td>Extreme</td>
</tr>
<tr>
<td>46 - 55 years (2057 – 2067)</td>
<td>4</td>
<td>High</td>
</tr>
<tr>
<td>56 - 70 years (2068 – 2082)</td>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>71 - 85 years (2083 – 2097)</td>
<td>2</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td>86 - 100 years (2098 – 2112)</td>
<td>1</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Note: *From a baseline year of 2012

Limitations of Data
The greatest limitation with the sea level rise data is that sea level rise is a gradual change and is variable within each region. One foot of sea level rise will inundate large portions of southern Florida but may have less of an impact in the coastal North and South Carolina where there are more established flood plains to handle the impact of the rising seas. The most frequent risk of sea level rise in the United States will not be a persistence of a higher shoreline, but the decreased area between infrastructure and shoreline. This will increase the rate of nuisance flooding in all of the regions with an “extreme risk” of sea level rise. Nuisance flooding leads to closure of roadways, degradation of infrastructure, disruption to public and business functions, and large economic losses. The other limitation is that this model does not capture the feedback of overall flooding in conjunction with sea level rise. It is strictly based off increases in tidal stations and not overall water volume increases. As flooding and sea level rise both increase, coastal areas will have a harder time functioning and will be forced to adapt to the shift in water.

5.4.5 Snow

Overview of Risk
There are three main indicators associated with snow: snow cover, snowpack, and snowfall. Each of the risks has different influencers and impacts, as described below.

Snow cover is defined as the amount of land that is blanketed by snow at any one time. Snow cover in North America has been declining over the past 4 decades. North American snow cover decreased by approximately 3,500 square miles per year from 1972 to 2013. In the Northern Hemisphere, snow cover is projected to decrease as a result of climate change under all RCP scenarios (Figure 5-7). The IPCC Fifth Assessment Report states there is high confidence that by
2100 spring snow cover in the Northern Hemisphere will be substantially lower than its current levels.\textsuperscript{130}

**Figure 5-7: Snow Cover Percent Change in the Northern Hemisphere (1986-2100)\textsuperscript{131}**

Notes: March – April average snow cover extent change in CIPM5 relative to 1986-2005

Reduced snow cover influences air temperatures, sea level, and storm patterns, and reduces the white area of the earth that reflects the sun. As a result, the earth’s surface will absorb more solar radiation, rather than reflect it, and thus the Earth will become warmer. Reduced snow cover can also affect the water supply.\textsuperscript{132}

*Snowpack* is defined as the depth of snow on the ground at any one time. From 1955-2013, snowpack measured in April in the Western United States declined at 75\% of the locations recorded, while some areas such as the Sierra Nevada Mountains, experienced an increase in the April snowpack.\textsuperscript{133} The IPCC Fifth Assessment Report states there is *medium confidence* that there will be an increase in snowpack in the coldest regions and a decrease in snowpack in the southern regions.\textsuperscript{134} Snowpack is dependent on several factors, including snowfall and snowmelt rates.

*Snowfall* is defined as the total amount of snowfall that occurs at any one time. Since the 1920s, the amount of snowfall has been declining in most regions of the United States, with the exception of the Rocky Mountains, Ohio Valley, and north-central United States, which are areas that have seen increased snowfall.\textsuperscript{135,136} Figure 5-8 shows the change in total snowfall in the United States from 1930-2007. Several studies have confirmed that wintertime precipitation is falling as rain in place of snow in the Western, Northwestern, and Central United States.\textsuperscript{137} Per the IPCC Fifth Assessment Report, current climate change projections predict an increase in overall precipitation that may lead to greater snowfall, and thus larger snowstorms, in colder regions and reduced snowfall in warmer regions.\textsuperscript{138}
A change in either the timing or the quantity of snowfall could affect water availability in the spring and summer. In addition, the amount of snowfall in a certain area directly influences the depth of snowpack and snow cover. Larger snowstorms could result in damage to infrastructure, cause transportation disruptions, and result in potential business and economic impacts.

Lockheed Martin experienced the impacts of increased snowfall during winter 2014, when its Northeast and Mid-Atlantic facilities were affected by large snowstorms. Temperatures were colder than normal, leading to increased heating requirements at the facilities. In addition, more snow fell than normal, resulting in unanticipated costs for snow removal. Furthermore, heavy snowfall and snowstorms caused disruptions all across the Northeast, Midwest, and Southeast which resulted in cancelled flights for employee travel.

**Data Analysis**
We did not include snow in our Excel-based vulnerability assessment tool due to the lack of available snow projection datasets, and the complicated nature of snow indicators. We found that historical data on past snow storms, when assessed at the regional level, can be very misleading due to geographic differences across a region. For instance, a state like California may have much snow in the Sierra Nevada Mountains, but very little in Southern California; however, region-level data does not account for this variation in risk level. Furthermore, the impacts of snow vary significantly based on a region’s degree of preparedness. A snow or ice storm in the Northeast, where this type of weather is frequent, may cause less disruption than a lower intensity storm in the South, where resources devoted to storm cleanup are fewer. Historical data on snow would also not capture this important component of vulnerability.
5.4.6 Temperature

Overview of Risk
According to the IPCC Fifth Assessment Report, global temperatures have been increasing, and will continue to increase, over time. According to the report, the 1980s, 1990s, and 2000s have been the three warmest decades since 1850. By 2100, global mean surface temperature is expected to increase 1.4°C to 3.1°C above the 1986-2005 average (under RCP6.0) or 2.6°C to 4.8°C above the 1986-2005 average (under RCP8.5). Figures 5-9 and 5-10 below illustrate this expected temperature change. As average temperatures shift, there is also an expectation that there will be an increase in the number of extreme warm days and decrease in extreme cold days.

Figure 5-9: Predicted Temperature Increases Under Multiple Emissions Scenarios

![Graph showing predicted temperature increases under multiple emissions scenarios.](image)

Figure 5-10: Predicted Changes in Surface Temperature by 2100

![Map showing predicted changes in surface temperature by 2100.](image)

Rising temperatures can have several effects on businesses. One risk is a decline in labor productivity. Extreme heat can increase worker fatigue and reduce the number of effective work hours each day: this situation is especially true in labor-intensive industries, such as construction and manufacturing. Higher temperatures will also result in greater cooling needs, which in turn will lead to higher energy consumption and greater costs for businesses. This is particularly relevant to urban areas, where heat islands can further exacerbate extreme conditions.
temperature events. In addition, with higher temperatures causing energy demand to increase across a region, utilities may have trouble providing energy to customers without interruptions.

At LMC’s Sunnyvale, California facility, high temperatures have led to increased demand for cooling over the last several years. Additionally, the stress on the water supply in the region has resulted in the need for the city to use more groundwater, thereby decreasing the overall quality of the water. This has resulted in less effective treatment of the water in the cooling tower of the Sunnyvale facility.

Data Analysis
To assess risks from expected changes in temperature, we relied on data from The American Climate Prospectus. This report is a product of the Climate Prospectus Team, which consists of individuals from several academic institutions, RMS Inc., and the Rhodium Group. The team relied on data derived from several climate models, including MAGICC and multiple models from CMIP5. For temperature projections, we again used the RCP 8.5 scenario, and we looked at the time periods 2020-2039 and 2040-2059 that the report provided. For current risk, we used the 1981-2010 baseline data provided, which the team obtained from the National Climate Data Center. For both current and projected risk, we specifically looked at extreme heat, with this factor being indicated by the number of days each year where temperatures reach 95°F or higher. To equate these values into vulnerability scores of 1-5, we created 5 equal ranges of the number of days each year with extreme heat, with the ranges based on the maximum number of such days found in the furthest time frame used in the study (2080-2099). Table 5-7, below, shows this index.

<table>
<thead>
<tr>
<th>Average Number of Extreme Warm Days Per Year</th>
<th>Vulnerability Score</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>25-50</td>
<td>2</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td>50-75</td>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>75-100</td>
<td>4</td>
<td>High</td>
</tr>
<tr>
<td>100+</td>
<td>5</td>
<td>Extreme</td>
</tr>
</tbody>
</table>

Limitations of Data
As with the water data, the validity of the current vulnerability scores depends on how well historical data represents present conditions, since there can be significant variability over time. Future temperature risk depends on the accuracy of the climate models the study used; however, the fact that both MAGICC and CMIP5 models are widely used, including in the IPCC reports, provides support toward their credibility. Furthermore, the projection data was not available for the exact time period for which we defined long-term risk (2041-2070), and so we selected the nearest time period available (2040-2059).

In addition to concerns about the data itself, there are limitations with using this data to draw conclusions about relative temperature risks across the United States. All regions are expected to have higher temperatures and a greater number of extremely hot days. However, for regions with
a naturally cooler climate (such as the Northeast versus the South), the region’s temperature risk will always appear smaller according to our vulnerability scores. For instance, the number of days above 95°F in the Northeast is estimated to be 12 by 2040-2059, while its average number of extremely hot days across 1981-2010 was only 2. In absolute value terms, this increase pales in comparison to the increase from 22 days above 95°F to 64 days above 95°F that will occur over the same time period in the South. However, the South may actually be better equipped to deal with extreme heat compared to the Northeast, because higher temperatures are more typical in that region. Therefore, a low temperature vulnerability score (a score of 1) does not necessarily mean temperature risk will not be a concern.

5.4.7 Tropical Cyclones

Overview of Risk
Tropical cyclones are a category of storms that originate over tropical or subtropical waters. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean because they use warm, moist air from near the ocean surface as “fuel”. Warmer ocean water (see Section 5.4.3 - Ocean Temperature) is a key factor for tropical cyclones, causing them to be stronger, and potentially more destructive. Once a cyclone loses its “tropical” characteristics (i.e. its primary energy source does not come from ocean heat), it is considered extra-tropical. There are four categories of tropical cyclones: tropical depressions, tropical storms, hurricanes, and major hurricanes.

- **Tropical Depression**: Winds speeds of 38 mph or less.
- **Tropical Storm**: Wind speeds of 39 to 73 mph.
- **Hurricane**: Wind speeds of 74 mph or higher, or a Category 1 or 2 on the Saffie-Simpson Hurricane Wind Scale.
- **Major Hurricane**: Wind speeds of 111 mph or higher, or Category 3,4, or 5 hurricanes on the Saffie-Simpson Hurricane Wind Scale.

Since the 1870s, NOAA has collected data on tropical cyclone occurrences in the United States, and since the 1970s tropical cyclones have been monitored using satellites. Figure 5-11 shows the occurrences of total named storms, hurricanes (Category 1, 2, 3), and major hurricanes (Category 4, 5) from 1850-2014, as recorded by NOAA. According to this data, since 1850, there has been an increase in frequency of recorded tropical storms, as well as an increase in the number of hurricanes of Category 3 or greater. However, there is uncertainty regarding the quality of the data from prior to the use of satellites, which has resulted in additional scientific studies to account for these uncertainties. As such, there is still debate as to whether there has been an increase in the frequency of storms over the last century. More reliable is the evidence that there have been more major hurricanes (Category 4 and 5) since the mid-1940s.
There is a consensus in the scientific community that climate change, and thus warmer sea surface temperatures, will increase the intensity (wind speed) of tropical cyclones. Global climate models show an increase in storm intensity over time.\textsuperscript{169,170} In the Atlantic Basin, models predict a 75\% increase in Category 4 and 5 storms.\textsuperscript{171} Alternatively, there is no consensus that climate change will increase the overall frequency of tropical cyclones. Some climate models project no change or even a reduction\textsuperscript{172} in the frequency of hurricanes, while other models show an increase in frequency.\textsuperscript{173,174} In the IPCC Fifth Assessment Report, it is stated that there is low confidence in the tropical cyclone frequency projections to the mid-21st century and low confidence in near-term tropical storm intensity projections.\textsuperscript{175}

Tropical cyclones are the most expensive natural catastrophes in the United States and account for a significant quantity of damage, injuries, and deaths.\textsuperscript{176} Eight of the ten costliest hurricanes recorded in the United States have happened since 2004. The two costliest hurricanes, Katrina in 2005 and Sandy in 2012, cost $125 billion and $65 billion, respectively.\textsuperscript{177} Additionally, tropical cyclones can cause significant disruptions to transportation and energy production, loss of business revenue, and damage to infrastructure. In addition, communities can be severely impacted when they no longer have access to food, healthcare, or clean water for a significant period of time. An increase in the intensity of tropical cyclones, combined with sea level rise, has the potential to make future coastal storms significantly more damaging.

\textit{Data Analysis}
We did not include tropical cyclones in our vulnerability assessment tool due to the following reasons: (1) the lack of scientific consensus regarding the link between climate change and tropical cyclone frequency; (2) the lack of available tropical storm projection datasets; and (3) the fact that tropical cyclones are a region-specific environmental risk, and thus they don’t apply to most regions in the vulnerability assessment tool.
5.4.8 Water Stress

Overview of Risk
Water scarcity has become a growing concern across the United States. A 2014 report by the U.S. Government Accountability Office found that 40 states anticipate water shortages in the coming decade. Two main reasons for this concern across the United States include a rising population and climate change. While a growing population increases water demand, climate change has more variable effects: examples include fostering droughts that reduce water availability, increasing floods that threaten water quality, and contributing to sea level rise that can contaminate freshwater aquifers. It should be noted, however, that total water use in the United States has actually declined notably since the 1980s, especially due to increasing water efficiency in industrial and commercial sectors, such as agriculture. Nonetheless, expectations are that water use would need to be reduced even further to avoid concerns over water availability as the United States’ population and economy continues to grow and the climate changes. For businesses, this growing water stress can create financial and reputational risks. As water availability decreases, the cost of water may rise, governments may restrict water use, disruptions may occur to manufacturing processes or across suppliers, and communities may protest corporate consumption of local water supplies.

LMC conducts annual water risk assessments using the World Business Council for Sustainable Development (WBCSD) Global Water Tool to identify which facilities are located in water-stressed regions, and uses the results to complete facility-level risk analyses and prioritize water initiatives by geographic region. Several of LMC’s facilities are located in water-stressed states, including California and Texas. In California, facilities are currently required to reduce water use by 25%, which has the potential to affect production at those facilities.

Data Analysis
To assess regional water risk, we used WRI’s Aqueduct Water Risk Atlas. This Atlas provides GIS datasets with global data on both current and projected water risks. By intersecting the GIS shapefiles with the nine U.S. regions, we were able to obtain estimates for the relative water stress in each region.

For current risk, we used WRI’s indicator score for baseline water stress. WRI defines baseline water stress as annual water withdrawals divided by annual freshwater availability: withdrawals were based on 2010 data from the Aquastat database from the Food and Agriculture Organization of the United Nations, and water availability was based on 1950-2010 data from a model called GLDAS-2. WRI then normalized these raw values for baseline water stress so each value was associated with an indicator score of 0 through 5 to represent a range from Low to Extremely High risk. Since WRI calculated water stress by catchment, we found the average of these baseline water stress indicator scores across all catchments in a region. By doing so, we were able to determine the current relative water stress across the United States. Our indexing system to create vulnerability scores for water stress is shown below in Table 5-8.
### Table 5-8: Explanation of Vulnerability Scores for Current Water Stress

<table>
<thead>
<tr>
<th>WRI Index System</th>
<th>Our Vulnerability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Water Stress Value</td>
<td>Meaning</td>
</tr>
<tr>
<td>0-1</td>
<td>Low (&lt;10%)</td>
</tr>
<tr>
<td>1-2</td>
<td>Low to Medium (10-20%)</td>
</tr>
<tr>
<td>2-3</td>
<td>Medium to High (20-40%)</td>
</tr>
<tr>
<td>3-4</td>
<td>High (40-80%)</td>
</tr>
<tr>
<td>4-5</td>
<td>Extremely high (&gt;80%)</td>
</tr>
<tr>
<td></td>
<td>Arid and Low Water Use</td>
</tr>
</tbody>
</table>

For projected risk, we used WRI’s data on water stress. We used water stress values pertaining to the emissions pathway RCP8.5 and socioeconomic pathway SSP2. SSP2 corresponds to a scenario where population growth, urbanization, and GDP growth all follow a business-as-usual pattern.\(^\text{192}\) To calculate water stress, WRI divided water demand by water supply in each basin. WRI obtained water supply values from multiple GCMs that were part of CMIP5.\(^\text{193}\) WRI estimated water demand using regressions that predicted water consumption based on country characteristics.\(^\text{194}\) Since WRI determined water stress scores at the catchment level, we again took the average water stress across all catchments in a region to determine regional water stress. We adopted WRI’s existing index to translate these values into vulnerability scores of 1-5, as shown in Table 5-9 below.

### Table 5-9: Description of Vulnerability Scores for Short-Term Water Stress

<table>
<thead>
<tr>
<th>WRI Index System</th>
<th>Our Vulnerability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Stress Value</td>
<td>Meaning</td>
</tr>
<tr>
<td>0-0.1</td>
<td>Low (&lt;10%)</td>
</tr>
<tr>
<td>0.1-0.2</td>
<td>Low to Medium (10-20%)</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>Medium to High (20-40%)</td>
</tr>
<tr>
<td>0.4-0.8</td>
<td>High (40-80%)</td>
</tr>
<tr>
<td>&gt;0.8</td>
<td>Extremely high (&gt;80%)</td>
</tr>
<tr>
<td></td>
<td>Arid and Low Water Use</td>
</tr>
</tbody>
</table>

**Limitations of Data**

There are several limitations to using this WRI data to assess current and projected water stress in the United States. In regard to current water stress, WRI relies on 2010 data for water withdrawals and historical data on water availability. Although this data selection likely leads to a reliable estimate of current water stress across the country, current risk could differ from historical results. As for projected water stress, the validity of these risk levels depends on the accuracy of the climate models WRI selected. All climate models combine different inputs, complex algorithms, and assumptions to predict future climate, so each has its own strengths and weaknesses. However, WRI’s use of models from the reputable CMIP5 Project—which were completed by the World Climate Research Programme and used in the IPPC assessments—lends credence to their reliability.
5.4.9 Wildfires

Overview of Risk
Wildfire refers to an unplanned damaging fire in a natural area such as forest, shrubs, grassland, or other vegetation communities.\textsuperscript{195} Wildfires typically result from a combination of factors, including hot and dry weather; the availability of branches, leaves, and vegetation; and human influences in the area. In the United States, the occurrence of large fires and total acres burned has been increasing (Figure 5-12).\textsuperscript{196,197} The year 2015 set the record for the most wildfires in the United States at 68,151 fires and 10,125,149 acres burned.\textsuperscript{198,199} This was an increase in nearly 5,000 fires and 7,000 acres burned from 2014. Since the 1980s, the frequency of large fires in the Western United States has increased 400\% and areas burned have increased 600\%.\textsuperscript{200} Climate change is expected to increase the frequency and intensity of large fires resulting from drier conditions, more available fuel for fires, and longer fire seasons.\textsuperscript{201,202}

Figure 5-12: Average Annual Area Burned and Number of Fires per Year in the United States\textsuperscript{203}

![Chart showing average annual area burned and number of fires per year in the United States.]

Notes: grey-yellow – average annual area burned; grey – number of fires per year

Annual losses resulting from wildfires were on average more than $1 billion from 2005-2014 (Figure 5-13).\textsuperscript{204} Fire suppression alone cost the Federal Government over $2 billion in 2015.\textsuperscript{205} The projected increase in wildfires, especially large wildfires, is expected to result in even greater losses and increased firefighting expenses in the United States. In addition, large wildfires may burn for weeks or months, resulting in significant impacts to the surrounding regions. This may result in utility or transportation disruption, lost work hours, and decreased business sales.\textsuperscript{206} Large wildfires can further contribute to global warming because they not only release large amounts of carbon into the atmosphere, but also they destroy trees and plants which act as carbon sinks.\textsuperscript{207}
Data Analysis
To analyze wildfire risk, we used data from a study from the *International Journal of Wildland Fire* by Barbero et al. (2015). We reached out directly to the corresponding author of the study, Renaud Barbero, a research associate at the University of Newcastle, to request the original data. The data was sent to us in MATLAB which we exported to Excel to conduct the analysis. The data presents the very large fire (VLF) potential over an area of 10,000 m² for the eleven Geographic Area Coordination Center (GACC) regions of the continental United States. VLFs are generally considered the top 5-10% of large fires in terms of area burned.

The data included both historical (1970-2010) and projected (2041-2070) VLF occurrence developed based on 17 GCMs to project changes from global warming under scenario RCP8.5.

For both historical and projected VLF occurrence, we used the ranges provided in the study (Figure 5-14) to translate the VLF potential for each region from the dataset into a score of 1 to 5. For example, if the mean VLF weeks was in the range 0.2 - 1, we assigned the region a score of 5, for “extreme risk”. Table 5-10 shows the ranges and the corresponding score that was assigned. Lastly, because the regions provided in the data are different than the NOAA climate regions in our risk tool, we had to average scores across some GACC regions and separate some GACC regions to fit the NOAA regions.
Figure 5-14: Range of Very Large Fire Weeks Expected

Table 5-10: VLF Ranges and Corresponding Vulnerability Scores

<table>
<thead>
<tr>
<th>VLF Potential (average weeks expected/10,000 m²)</th>
<th>Our Vulnerability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
</tr>
<tr>
<td>1 – 0.2</td>
<td>5</td>
</tr>
<tr>
<td>0.1 – 0.2</td>
<td>4</td>
</tr>
<tr>
<td>0.04 – 0.1</td>
<td>3</td>
</tr>
<tr>
<td>0.02 – 0.04</td>
<td>2</td>
</tr>
<tr>
<td>0.00 – 0.02</td>
<td>1</td>
</tr>
</tbody>
</table>

Limitations of Data

As is explained in the Barbero et al. study (2015), many uncertainties exist in this type of climate modeling. Alternative models using a different combination of factors could result in different projections of changes in VLFs in the United States. Additionally, the climate models used depend on a specific number of factors, including temperature, relative humidity, precipitation, drought, water deficit, and fire danger, among others, all of which are projected as well. If one or more of those factors were to change, the VLF occurrence would likely change as well. Lastly, this study was the first study of its kind that modeled VLF occurrence to account for the varying relationships between climate and fire; thus, there have not been other models yet to repeat the results. All that being said, the report was reviewed and published in *International Journal of Wildland Fire* and the researchers uses CMIP5 climate models (the same models used by the IPCC for their projections), both of which legitimize the results.
6 INTERACTIVE VULNERABILITY ASSESSMENT TOOL

6.1 Overview of the Vulnerability Assessment Tool
The accompanying tool and model aggregator prepared for LMC incorporates a variety of indexed data sets stemming from existing climate models and historical data. The tool was built in the Microsoft Excel platform, and incorporates various data collection algorithms housed in Visual Basic structures. The choice to build and construct within the Excel platform will allow for users to run the tool in a ubiquitous environment, and gives the Duke team the support from the advanced built-in functionality of the Microsoft system.\textsuperscript{215}

To aid in user ability and familiarity, a metadata tab is included in the vulnerability assessment tool to provide users with information regarding parameters, results, and interpretation of numeric values.

6.2 Use of the Vulnerability Assessment Tool
The tool takes in three inputs and parameters, all supplied by the user, and returns data and visualizations based off of the selections. In conjunction with the output and corresponding geographical heat map of the continental United States, the tool also directs users to completed calculations used to arrive at the indexed data values for each risk.

Through each iteration and run of the tool, users can see vulnerability scores associated to a variety of environmental risks, in differing time scenarios. These risk values are segmented by geographical region.

\textbf{Figure 6-1: Visualization of the Tool’s UserForm Object Prior to Run}

\begin{center}
\includegraphics[width=0.4\textwidth]{DukeClimateModel.png}
\end{center}

6.3 Parameters of the Tool
The tool incorporates a variety of parameters. To input each parameter, the tool incorporates a UserForm object inherent to the Excel environment. A UserForm object is a digital interface that makes up part of an application’s visual dashboard.\textsuperscript{216,217} In this tool, parameters regarding region, time scenarios, and environmental risks are included using combination boxes for selection.
1. Region Parameter

Users select a geographical region from the continental United States. The regions used in this tool correspond to the U.S. Climate Regions used by NOAA’s National Centers for Environmental Information. These nine regions that cover the continental United States were identified through climate analyses and are useful for placing weather and climate-related anomalies in a historical context. 218

2. Risk Type Parameter

Users select an environmental risk in each iteration of the tool. Included risks were chosen using a combination of variables, including the ability to procure sufficient data, economic factors from potential risk-associated events, and miscellaneous information provided by LMC.

3. Scenario Parameter

Users select a time scenario parameter of which to view the data. For the purposes of this project, and in conjunction with existing and available data, the Duke team identified three time scenarios to incorporate into the tool: current, short-term, and long-term. The user will enter in the UserForm object whether they wish to incorporate the ‘current’, ‘short-term’, or ‘long-term’ scenario. The ‘short-term’ time scenario is defined as the periods from 2020 through 2040, while the ‘long-term’ time scenario is defined as 2041 through 2070. These time frames were determined based on the availability and quality of the data.

Figure 6-2: Sample Screenshot of Output from the Tool

<table>
<thead>
<tr>
<th>Model Inputs:</th>
<th>Run</th>
<th>Clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Run</td>
<td>Clear</td>
</tr>
<tr>
<td>Risk</td>
<td>Run</td>
<td>Clear</td>
</tr>
<tr>
<td>Time Scenario</td>
<td>Run</td>
<td>Clear</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link to Metadata and Calculations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Scenario</td>
</tr>
<tr>
<td>Vulnerability Score</td>
</tr>
<tr>
<td>Region Rank</td>
</tr>
<tr>
<td>Spread of Data</td>
</tr>
<tr>
<td>Run-Time</td>
</tr>
</tbody>
</table>
6.4 Outputs of the Tool

Each run of the tool provides a series of outputs and data visualizations. Upon running the tool, users are prompted with values corresponding to the selected time scenario (determined from inputs in the UserForm object), regional rankings depending on selected parameters, and standard deviations for measuring the spreads in each type of regional risk (see Figure 6-2). Users are also shown data visualizations of the run iteration, which are constructed and executed through Visual Basic. These visualizations include charts showing visual representation of the returned scores from Figure 6-2.

**Figure 6-3: Sample Screenshot of Geographical Heat Map**

![Geographical Heat Map](image)

The third component of the tool outputs is the geographical heat map (Figure 6-3). For the purposes of this project, the Duke team created an interactive heat map that updates depending on the parameters entered by the user. The heat map is intended to provide further data visualization measures, as well as a comparison between all of the regions.

*Future Iterations and Enhancements of the Tool*

The existing tool can serve as an aid for decision-makers at LMC related to selecting locations for operations, supplier selection and prioritizing resources for resource conservation efforts. While the tool currently incorporates a variety of variables subject to the scope of the project, the following areas serve as points of interests for future enhancements.

- The geographical heat map shows scores based upon regional values, but was constructed to be more flexible in its operations. Each state on the map serves as an independent object, and so future iterations can incorporate state-specific vulnerability scores rather than only regional vulnerability scores.
• The current tool encompasses the continental United States. Future iterations towards enhancements should incorporate further regions including, but not specific to, Hawaii, Alaska, and regions outside the United States, such as Europe and Asia.

• The current tool incorporates a series of six environmental risks and three time scenarios. Future iterations towards enhancements should look to increase the scope of risk factors that are utilized, as well as the time scenarios.

• As climate projection data changes in the coming years, the data in the model will need to be updated to incorporate this new data.

7 RESEARCH FINDINGS

7.1 Climate Change-Related Risks Affecting Each Climate Region
The following sections include an overview of each of the nine climate regions, a summary of the environmental risks output from the Excel-based risk tool, and the potential impacts of those risks.

7.1.1 Northwest

Overview of Region
Washington, Oregon, and Idaho are the three states that make up the Northwest region. The 2010 population for this region was 12.1 million. The U.S. Census Bureau anticipates significant population growth in the Northwest: it expects population will rise 45.42% from approximately 10.6 million in 2000 to 15.4 million in 2030. The Northwest is home to many fast-growing cities, including Seattle, OR and Boise, ID. The U.S. Census Bureau listed Boise, ID as one of the twenty metro areas in the United States with the highest population growth between July 2013 and July 2014. Meanwhile, across that same time period, Seattle, OR had the third highest population growth rate among the fifty largest cities in the United States.

Geography across the Northwest varies, since the region includes rivers, deserts, forests, plains, mountains, and coastline. The Cascade Range cuts through Oregon and Washington, while the Rocky Mountains pass through Idaho. Several major rivers, including the Columbia River and Snake River, also are present.

Climate in the coastal portion of the Northwest region is typically associated with frequent rain and mild temperatures. To the east of the Cascades, rainfall is lower and temperatures vary more widely. Snow falls heavily in the Cascades of Oregon and Washington, and Idaho also receives notable snowfall each winter.
Summary of Risks

Table 7-1: Summary of Risks for the Northwest Region

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Moderate</td>
<td>Extreme</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Extreme</td>
<td></td>
</tr>
</tbody>
</table>

Currently, the Northwest’s primary risks are flooding and water stress. Climate change will magnify water stress, bringing this risk to an extreme level. Climate change will also intensify the risk of wildfire in the region and bring about a moderate risk in sea level rise.

Impacts of Risks

Water stress is one of the greatest concerns for the Northwest. As temperature rises, what would be snowfall in the Cascades will instead fall as rain, in turn leaving less snowpack to provide meltwater during summer months. Timing of streamflow will also change: as winter rain increases and snowmelt occurs earlier in the spring, streamflow will decline across the spring and summer seasons. This transition will increase water stress in the Northwest, a change that is expected to affect the region’s agricultural sector as well as possibly affect hydropower supply.

Higher temperatures and less summer snowmelt will also significantly increase wildfire risk. Under a medium emissions scenario, the area in the Northwest that is burned by fire will more than double by the 2040s compared to the 1916-2006 baseline—a change that would lead to 1.1 million acres being burned annually.

Increased risk of sea level rise and coastal flooding also will impact the region. These two factors can erode shorelines, damage property, and disrupt wastewater infrastructure, as well as interrupt key ports, roads, and railways.

7.1.2 West

Overview of Region

The West region includes California and Nevada. LMC has several facilities in the West region, including one in Sunnyvale, California and one in Palmdale, California. In addition, LMC has five Tier 1 suppliers and two Tier 2 suppliers in Southern California.

The geography of the region varies quite a bit, ranging from the 840-mile-long California coastline, to the Sierra Nevada Mountains, and deserts of Southern California and Nevada. The deserts of the region are some of the hottest areas of the United States. Death Valley, in Southern
California, set the record for the highest temperature ever recorded at 134 °F in 1913.\textsuperscript{243} The Central Valley of California is a crucial region for agriculture in the United States, providing 25\% of the food supply, and 40\% of its fruits and vegetables.\textsuperscript{244}

California and Nevada have a combined population of about 40 million people, as of the 2010 census.\textsuperscript{245} The population is mostly concentrated in the coastal cities of San Francisco, Los Angeles, and San Diego. The population is expected to increase to 47 million in California and 4 million in Nevada by 2030.\textsuperscript{246}

\textit{Summary of Risks}

\textbf{Table 7-2: Summary of Risks for the West Region}

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Moderate</td>
<td>Extreme</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Extreme</td>
<td></td>
</tr>
</tbody>
</table>

Per the results of the tool, the West region currently faces a moderate risk of drought, water stress, and temperature. The reason the current risks are “moderate” is because each vulnerability score is averaged over the entire region, and, therefore, much of the variability within a region is buried. Flooding is currently a low to moderate risk for the region but is expected to become more of an issue particularly as precipitation becomes more variable and sea level rise affects coastal areas.\textsuperscript{247} With climate change, water stress is expected to become an extreme risk for the region in the short-term. Due to limited data availability for water stress projections, we were not able to determine a risk level for water stress in the long-term. Similarly, we were not able to determine a risk level for drought in the short- and long-term. However, it is expected that both water stress and drought will continue to be significant issues for the West region.\textsuperscript{248,249}

Wildfire is an extreme risk for the region, particularly for the forest regions of Northern California, near San Bernardino, and the scrubland in Southern California.\textsuperscript{250} Lastly, sea level rise is a high risk for the West region, specifically the coastal areas of California, including the San Francisco Bay Area, Los Angeles County, and Orange County.\textsuperscript{251,252} Flooding and sea level rise could impact LMC facilities located in coastal zones; however, a facility-level assessment would need to be conducted to determine the particular risks to specific facilities.

\textit{Impacts of Risks}

Water stress and drought are the most significant risks facing the West region. Water availability will not only impact the large population of California, but it will impact agriculture in the Central Valley, as well as power production and manufacturing.\textsuperscript{253} The impacts of water scarcity
are far-reaching and will significantly impact businesses, many of which are already experiencing water restrictions, higher water costs, and more stringent regulations.\textsuperscript{254}

With higher temperature and decreased water availability, wildfires will also become more severe and more difficult to control. Wildfires are hugely damaging to infrastructure, property, business and tourism, and the community.\textsuperscript{255} Additionally, wildfires can cause human health impacts, such as respiratory illness, due to reductions in air quality. In California, the costs of wildfire suppression have increased drastically over the past several decades.\textsuperscript{256} The Insurance Information Institute’s list of the “Top Ten Most Wildfire Prone States” includes both California (#1) and Nevada (#10).\textsuperscript{257}

Sea level rise and coastal flooding have the potential to significantly impact communities along the California coastline. Infrastructure, industrial facilities, schools, homes and natural areas are all vulnerable to sea level rise. Sea level rise will likely lead to transportation disruptions, evacuations, destruction of property, and potentially the loss of life.\textsuperscript{258} \textit{Sea Level Rise Vulnerability Study for the City of Los Angeles} (2013) found that roads, water systems, cultural assets, and low-lying communities in the City of Los Angeles are vulnerable to sea level rise while the Port of Los Angeles and the City energy facilities have relatively low vulnerability to sea level rise.\textsuperscript{259}

7.1.3 Southwest

\textit{Overview of Region}

Arizona, Colorado, New Mexico, and Utah are the four states included in the Southwest region. LMC has several facilities in the Southwest, including a facility in Waterton, Colorado.

The Southwest has an arid to semi-arid climate and is comprised of some of the driest, hottest locations in the United States. The region is primarily desert and plateaus, with mountains in northern New Mexico and central and western Colorado. The Colorado River is an important water feature in the region, flowing from Colorado through Southeastern Utah, and into Arizona.

The four states had a combined population of 16.2 million people in 2010\textsuperscript{260} Arizona, Utah and New Mexico are three of the fastest-growing states in the country,\textsuperscript{261} and the Census Bureau’s projections indicate that the region will reach a combined population of 22 million by 2030, with most of the population growth in Arizona.\textsuperscript{262}
### Summary of Risks

#### Table 7-3: Summary of Risks for the Southwest Region

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>Flood</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>Temperature</td>
<td>Low to Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Water Stress</td>
<td>Extreme</td>
<td>Extreme</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

The Southwest region is expected to continue to face an extreme risk of water stress, specifically as the region experiences increased temperatures. Although we were not able to output the drought vulnerability score from the risk tool, existing research predicts an increase in drought in the region, particularly in Arizona and New Mexico. Flooding is not currently a major risk for the Southwest region, with the exception of areas directly adjacent to the Colorado River. Climate change is expected to influence the timing, frequency, and intensity of floods, and as a result, Eastern Colorado, along the eastern side of the Rocky Mountains, is expected to have a higher risk of flooding. In the long-term, wildfire is expected to be a high risk for the region, particularly in areas of northern Utah and northeastern Colorado. Lastly, sea level rise and tropical storms are not expected to be risks for this region of the United States.

#### Impacts of Risks

Similar to the West region, water stress and drought are the most significant risks facing the Southwest region. The region depends on water for the growing populations of Arizona, Utah, and New Mexico, the regional economy, including tourism and recreation, and hydroelectric power at Lake Powell and Lake Mead. Water stress and drought have the potential to impact LMC facilities located in the Southwest region; however, a facility-level assessment would need to be conducted to determine the specific risks to these facilities.

With increases in wildfire risk, the Southwest region could face damage to its infrastructure, economy, and communities. The Insurance Information Institute’s list of the “Top Ten Most Wildfire Prone States”, as previously referenced above, includes Arizona (#7), Utah (#8), New Mexico (#9), and Colorado (#3). The Denver-Aurora-Lakewood region of Colorado is particularly vulnerable to wildfires that could spread from the mountainous region to the west.

#### 7.1.4 Northern Rockies and Plains

#### Overview of Region

Montana, North Dakota, South Dakota, Wyoming, and Nebraska are the five states in the Northern Rockies and Plains region. This region has a small population compared to the other regions assessed: the population was 4.3 million as of 2010. However, the population appears
to be growing: this 2010 population was a 7% increase over the population in 2000 and exceeds the U.S. Census Bureau’s estimated population of 4.27 million in 2030.\textsuperscript{271}

The geography of the region includes mountains in the west across Montana and Wyoming, and flat plains along the east in Nebraska and the Dakotas.\textsuperscript{272} This region is also home to the longest river in the United States: the Missouri River. Aside from the mountains, the region has a semiarid climate and low levels of annual precipitation.\textsuperscript{273,274,275} Seasonal changes bring extreme cold in the winter and heat in the summer.\textsuperscript{276,277} Portions of this region, including Nebraska and South Dakota, are also part of Tornado Alley.\textsuperscript{278} The Rocky Mountains themselves, however, have varying climates depending on the elevation and season: depending on these two factors, temperatures may range from below freezing to moderate, and precipitation may range from heavy snow to rain.\textsuperscript{279}

\textit{Summary of Risks}

\textbf{Table 7-4: Summary of Risks for the Northern Rockies and Plains Region}

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Extreme</td>
<td>Extreme</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

The Northern Rockies and Plains region currently has extreme water stress and moderate drought risk. With the climate changing, water stress is expected to remain high and wildfire is expected to become severe. These are the two main threats identified through our data analysis.

Although current flood risk is listed as low to moderate in the current-term (and we were unable to find projections for the short- or long-term), expectations are that heavier precipitation in this region will worsen flooding as well.\textsuperscript{280,281} Drought risk will also persist,\textsuperscript{282,283} especially since heavier precipitation will tend to occur in cooler months.\textsuperscript{284} Similarly, while the number of days with extreme heat will not be as high as that in other regions, higher winter and summer temperatures are expected in the region,\textsuperscript{285} as well as more days with very high temperatures.\textsuperscript{286}

\textit{Impacts of Risks}

This region is heavily involved in agriculture and energy production (including coal, oil, and biofuels), all of which consume high quantities of water.\textsuperscript{287} Availability of water will only become more strained as energy demand rises as a result of warmer temperatures, floods threaten water quality, and snowmelt from the Rocky Mountains declines.\textsuperscript{288,289} This water stress could have far-reaching social and economic consequences, including higher water costs, government restrictions on water consumption, interrupted power supplies, and disruptions to water-
dependent industries, such as agriculture. Wildfire severity is also increasing in this region as a result of warmer and drier summers. A higher number of wildfires will damage forests, disrupt the wildlife they support, and reduce water provisions from forest regions. This situation may further magnify the risk of water stress in the Northern Rockies and Plains region.

7.1.5 Upper Midwest

Overview of Region
The Upper Midwest region includes Iowa, Michigan, Minnesota, and Wisconsin. One of LMC’s Tier 1 suppliers evaluated for this project is in Burnsville, Minnesota.

The climate of the Upper Midwest varies quite a bit between summer and winter; in the summer, temperatures can reach 90° F and in the winter, down to 10° F. All states in the region receive a significant amount of snowfall during the winter months of December through March. The region, particularly the states of Iowa and Minnesota, consist of plains and rolling hills. The Great Lakes—Superior, Michigan, and Huron—and the Mississippi River are important water features of the region. The Mississippi River flows from Minnesota, through Iowa, and further South to the Gulf of Mexico. Iowa has large areas of fertile land, and thus is a large agricultural region, producing corn, soybeans, hay, wheat, and oats for the United States.

As of 2010, the four states had a combined population of 24 million. Much of the population is concentrated in the metropolitan areas of Detroit, Michigan (4.3 million), Minneapolis-St. Paul, Minnesota (3.4 million), and Milwaukee, Wisconsin (1.6 million). The U.S. Census Bureau expects the population of the Upper Midwest region will rise to 26 million by 2030.

Summary of Risks

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Low to Moderate</td>
<td>Moderate</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

The Upper Midwest region currently faces low to moderate risks of drought and water stress, and a moderate risk of flooding. With climate change, water stress will become a moderate risk for the region. Temperature and wildfire are projected to be low risks for the region.

Impact of Risks
Water stress and flooding appear to be the most significant risks to affect this region based on the data assessed. Water stress has the potential to impact water availability, disrupt agricultural
production in Iowa, and affect businesses in the region. For businesses, this means decreases in water allotments, higher water costs, and more stringent regulations, all of which can affect operations. Flooding has the potential to impact low-lying areas adjacent to the large water sources in the Upper Midwest, such as the Great Lakes and the Mississippi River. Flooding can result in sewer overflows and sewage spills into the Great Lakes. Flooding can damage infrastructure and property, and cause transportation and distribution issues for those areas.

7.1.6 Central (Ohio Valley)

Overview of Region
The Ohio Valley region includes Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, and West Virginia. One Tier 1 supplier evaluated for this project is in Vandalia, Ohio and one Tier 2 supplier is in Addison, Illinois.

The Ohio Valley faces extreme heat and cold, along with heavy precipitation; this climate results from the region’s exposure to both cold Arctic air and warmer, humid air from the Gulf of Mexico. The amount of precipitation is similar across the year; in the wintertime, precipitation turns to snow. Most of the region consists of low-lying land with some mountainous regions in Tennessee and West Virginia. Outside of the large cities in the region—such as Chicago, IL, Cleveland, OH, and Kansas City, MO—are expansive agricultural lands and multiple rivers, such as the Ohio River, the Mississippi River, and Missouri River.

The combined population of the seven states was 49.4 million in 2010. The population of the region is expected to grow to 52 million by 2030; however, West Virginia is projected to see a decline in population.

Summary of Risks

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>High</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low to Moderate</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Low</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

Ohio Valley currently has a low risk for drought, water stress, wildfires, and extreme temperatures. It is expected that temperatures in this region will rise to a low to moderate risk level. The most significant risk for the region is the high risk of flooding, particularly in low-lying areas and near the Mississippi, Missouri, and Ohio Rivers. Although we did not find projection data for flooding, heavier precipitation in this region, which is predicted to occur over time, will likely lead to increased flooding.
Impacts of Risks
Increased precipitation and flooding can damage infrastructure and property, displace residents, and cause disruptions to normal business operations. The changes in rain patterns, which are trending towards drier conditions in the summer and increased winter precipitation, will stunt the summer growth and bring rain where there is less agricultural productivity. Temperature increases bring increased risk of heat stroke and other heat-related illnesses, and there is also a greater risk of air pollution, particularly in the summer months when air remains stagnant. The increased temperatures will also impact livestock and crops and will increase the prevalence of pests that can destroy crops. This could potentially result in large impacts to the agricultural production of the region.

7.1.7 Southeast

Overview of Region
Virginia, North Carolina, South Carolina, Georgia, Florida and Alabama are included in the Southeast region. LMC has several facilities in the Southeast region, in the following locations: Ocala, Florida; Orlando, Florida; Riviera Beach, Florida; Troy, Alabama; Marietta, Georgia; and Virginia Beach, Virginia.

The Southeast climate is humid and subtropical, with hot summers and cool winters. There are occasional snow events in the winter, and summer can consist of high intensity storms and hurricanes. The region has mountainous regions to the West and large expanses of coastal plains to the East.

Approximately 48 million people live in these six states combined, with much of the population residing in Atlanta, GA and Miami, FL. The Southeast is a fast-growing region; it is anticipated the region will reach a population of 73 million in 2030. Florida alone is expected to double its population to reach 29 million by 2030. By 2060, the Piedmont region between Charlotte, NC and Atlanta, GA is predicted to become a megalopolis, or one continuous urban corridor.

Summary of Risks

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>Flood</td>
<td>High</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low to Moderate</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Low to Moderate</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>
The Southeast region currently faces a high risk of flooding, low to moderate risks of water stress and drought, and a low risk of extreme temperature. Sea level rise is expected to be an extreme risk for the Southeast, particularly the coastal communities. Hotter temperatures are also projected to become a risk for this region. Lastly, although we did not analyze tropical storm risk in our tool, tropical storms are expected to increase in intensity, which will impact the Southeast region.

**Impacts of Risks**
The Southeast’s most significant risks are related to sea level rise and flooding, particularly because much of the population in this region lives on the coast. These changes could potentially result in property damage, displacement of residents, shoreline erosion, and disruptions to coastal infrastructure. Though the area is expected to experience an overall increase in rainfall, there will also be more variability in when the rainfall occurs. This situation lends to an increase in flooding events. These impacts are expected to be further exacerbated by the huge population grow that is expected in the Southeast region.

In addition, tropical storms are a significant risk for the region. Tropical storms result in extensive infrastructure loss, flooding, and periods of business and societal disruptions, and tropical storms are anticipated to only get worse with climate change. North Carolina and Florida are two of the three states most frequently hit by hurricanes, according to the Insurance Information Institute. It is estimated that in the past 10 years alone there have been $110.4 billion dollars of insured losses from hurricanes in the United States.

### 7.1.8 South

**Overview of Region**
The South region consists of Arkansas, Kansas, Louisiana, Mississippi, Oklahoma, and Texas. Of the locations evaluated for this project, LMC has three facilities and four Tier 1 suppliers in the South region. The six states that make up the South region have a combined population of 37 million. The region is expected to experience large population growth, reaching 51 million by 2030. Texas alone is expected to add more than 8 million new residents by 2030 as compared to the 2010 population.

The South region consists of low-lying plains and wetlands, and overall has a relatively flat topography. The climate of the South is hot and humid in the summers and mild and cool in the winters. Snowfall can occur in the northernmost portions of this region (in Oklahoma). The summer brings heavy rainfall and tropical storms. Texas, Oklahoma, and Kansas are part of the area coined “Tornado Alley” that experiences a high frequency of tornados each year.
Summary of Risks

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>High</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low to Moderate</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Moderate</td>
<td>Extreme</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

The South region currently faces a high risk of flooding, a moderate risk of water stress, a low to moderate risk of drought, and a low risk of extreme temperature. In the face of a changing climate, sea level rise is expected to be an extreme risk for the South region. Although we did not analyze the data in our tool, tropical storms are expected to increase in intensity, which will impact the South region, particularly Louisiana, Mississippi, and Texas. Tornados could also be an issue for the region.

Impacts of Risks
The South region will face significant impacts from sea level rise and flooding, which can lead to property damage for businesses and residents, as well as disrupt coastal infrastructure. Increased flooding events in this region will have a significant impact on the large number of refineries along the coastal regions of Texas and Louisiana.

The South will also experience higher temperatures, and face increased water stress. Water stress can lead to restricted water use, higher water costs, and interruptions to businesses’ production schedules and supply chain. Temperature increases bring increased risk of heat stroke and other heat-related illnesses, particularly for those who work outdoors.

Similar to the Southeast region, tropical storms are a significant risk in the South region. Louisiana is one of the three states most frequently hit by hurricanes, according to the Insurance Information Institute. As tropical storm intensity increases with climate change, potential property damage and loss of life may increase.

7.1.9  Northeast

Overview of Region
The Northeast includes the following eleven states: Massachusetts, New Hampshire, Vermont, New York, Pennsylvania, Maryland, Delaware, New Jersey, Connecticut, Rhode Island, and Maine. As of 2010, the Northeast had a population of approximately 62 million. The U.S. Census Bureau estimates that in 2030 the region’s population will reach 65.7 million. Six of the LMC facilities assessed in this project are located in this region, along with three Tier 1 suppliers and two Tier 2 suppliers.
Geographically, the region is home to several major cities, including New York and Boston, but also has extensive rural and forested land. Two major mountain ranges, the Adirondacks and the Appalachian Mountains, cross through this region. In addition to having numerous rivers, like the Connecticut River and Hudson River, much of the Northeast is along the coast of the Atlantic Ocean.

There is much variation in climate within the region. Summer months bring heat and humidity, while winter months bring cold temperatures and snow. Coastal areas in the Northeast can also be subject to autumn hurricanes and winter nor’easters.

**Summary of Risks**

<table>
<thead>
<tr>
<th>Environmental Risk Type</th>
<th>Vulnerability Score</th>
<th>Current</th>
<th>Short Term (2020 - 2040)</th>
<th>Long Term (2041 - 2070)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Low to Moderate</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>High</td>
<td>No Data</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>NA</td>
<td>NA</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>Water Stress</td>
<td>Moderate</td>
<td>High</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td>Wildfire</td>
<td>Low</td>
<td>No Data</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>

Currently, flooding and water stress are the main risks in the Northeast region, based on the data assessed. Over time, the risk of sea level rise emerges, and the risk of water stress intensifies. Specific to water stress, the reason this risk is shown as “high” in the short-term is due to the significant number of areas with high and extreme risk in the Northeast. Although there are also areas in the Northeast with a low risk of water stress, when all of the areas in the region are averaged, the result hides this variability within the region.

Across all time periods, wildfire is not a concerning risk. While extreme heat maintains low risk across all years, higher temperatures and more heat waves are predicted to occur in the Northeast during the 21st century. However, the scores are still low because relative to other regions, the risk will be smaller (see Section 5.4.6 – Temperature, Data Limitations). Although we were unable to obtain projection data for flood or drought risk, multiple studies predict both will increase in the region over the coming decades.

**Impact of Risks**

These environmental risks will have many effects in the Northeast. Higher temperatures and more heat waves in the region are expected to cause heat stress and lessen air quality, particularly by fostering the creation of ground-level ozone and increasing the productivity of allergen-producing plants. Concerns also exist about the stress higher temperatures will place on energy production, which could lead to blackouts. As for flood risk, flooding from sea level rise, hurricanes, nor’easters, and heavy precipitation can damage property and cause injury. Coastal flooding, in particular, may interrupt transportation routes (including highways, airport
runways, subway systems, and shipping ports) and impair wastewater treatment plants in the region. Increased risk of coastal flooding, especially with sea levels rising, may also lead to higher insurance costs.

8 DISCUSSION AND RECOMMENDATIONS

From this analysis, we have provided an overview of the environmental- and climate change-related risks across the United States. A summary of the key risks in each region, along with the number of facilities and supplier locations assessed and the corresponding LMC employee counts, can be found in Table 8-1 below.

**Table 8-1: Summary of Key Risks and Facility and Supplier Counts by Region**

<table>
<thead>
<tr>
<th>Region</th>
<th>High &amp; Extreme Risks</th>
<th>Number of Major Facilities</th>
<th>Number of Employees at the Major Facilities</th>
<th>Number of Tier 1 Suppliers</th>
<th>Number of Tier 2 Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>Flood (C)</td>
<td>3</td>
<td>15,378</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Water Stress (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast</td>
<td>Flood (C)</td>
<td>6</td>
<td>11,183</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>Flood (C)</td>
<td>6</td>
<td>8,660</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Water Stress (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>Water Stress (S)</td>
<td>2</td>
<td>7,398</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sea Level Rise (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southwest</td>
<td>Water Stress (C&amp;S)</td>
<td>1</td>
<td>4,157</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwest</td>
<td>Water Stress (S)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Midwest</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ohio Valley</td>
<td>Flood (C)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Northern Rockies &amp; Plains</td>
<td>Water Stress (C&amp;S)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Wildfire (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From this summary table, several conclusions can be drawn. First, the two main potential risks in the current time period and short-term time period are water stress and flooding, based on the data assessed. Sea level rise and wildfire risk appear in several regions, but are only significant in the long-term. In addition, temperature risk is noticeably absent from this summary table, except for in the West. Although we found that extreme heat will rise across all regions (with the greatest number of days with extreme heat occurring in the South, Southwest, and West), we
found that extreme heat will become most severe as we approach 2100, which is beyond the time-frames we considered.

Therefore, we recommend that LMC focus its resiliency efforts on addressing flooding and water stress risks. One or both of these potential risks appear in each region where LMC has many facilities, employees, and suppliers, including the South, Southeast, Northeast, and West. In each of these locations, sea level rise is also a potential risk, meaning that in the long-term flood risks in these regions may worsen.

Before taking action to address any of these vulnerabilities, we recommend that LMC perform a deeper dive into the local risks faced at each facility and supplier. Our regional-level vulnerability assessment hides the variation in vulnerability across a region, which is important to understand when determining the true risks to LMC’s operations. Therefore, we suggest that LMC select a small number of facilities or suppliers in one or more of the four regions identified above and have a new project team perform a more comprehensive analysis of the potential risks the facilities and suppliers in that region face. Given that flood and water stress were found to be some of the most prominent near-term potential risks, LMC may want the team to focus this localized assessment on these two potential risks.

In fact, given LMC’s extensive assessment of water stress and current efforts to reduce water consumption, we recommend focusing on flood risk. More advanced tools, such as GIS, can provide a more accurate description of flood risk in a particular location, including direct damage to infrastructure or interrupted transportation routes. Meanwhile, LMC can continue its comprehensive efforts to reduce its vulnerability to water stress. Through its “Go Green” initiative, LMC has committed to reducing water use 30% below 2010 baseline levels, and, as of 2014, had already reduced its water consumption by 21%. In addition, LMC continues to seek opportunities to reduce water use at sites located in regions of high water stress. For example, the company recently conducted water balances at its three largest facilities in California to identify ways to increase water conservation and water re-use as these sites.

In regard to planning for future programs, LMC should also pay close attention to its operations in the West. The region has the greatest number of high or extreme risks, especially when long-term risks are considered. In addition to sea level rise (and the associated flood risk), the region faces high risk of wildfire, extreme heat, and water stress. The region is also the site of several suppliers for the C-130 program, which could mean possible disruptions to this supply chain over time.

Although we have identified certain risks as being more common or imminent, there are likely to be variations within a given region in regard to which risk is most important. Therefore, in the following section we have outlined possible adaptation efforts that LMC can pursue to address the six environmental risks we assessed.

In summary, we believe LMC can build upon our preliminary assessment through the following:

1) Focus resiliency efforts on addressing potential flood and water stress risks in the short-term in regions where these risks have been identified;
2) Perform a deeper dive into the local risks at each facility and supplier location; and
3) Pay close attention to LMC and supplier operations in the West region due to the greatest number of high or extreme risks, especially in the long-term.

8.1 Adaptation Strategies

To lower its vulnerability to current and projected climate change-related risks, LMC can implement adaptation efforts to address the greatest potential risks across its facilities and suppliers. Whether a particular adaptation measure is worthwhile for the company to pursue will depend on the severity and probability of the risk, the financial effect that risk could have on the company, and the cost of the adaptation measure. Whether a facility is owned, leased, or government-owned will also be a determinant in which adaptation options are allowed or whether federal insurance coverage makes the up-front cost of adaptation worthwhile.

In their 2008 report *Adapting to Climate Change: A Business Approach*, the nonprofit Center for Climate and Energy Solutions (C2ES) recommends asking three questions to determine whether a company should adapt to climate change. These questions include: 1) “Is the business sensitive to climate risk?”, 2) “Is there an immediate threat? Or are long-term assets, investments, or decisions being locked into place?”, and 3) “Is a high value at risk if climate change impacts occur?” Figure 8-1 below outlines this recommended thought-process. If LMC—after using the results from our vulnerability assessment tool and any further risk assessments—decides to adapt its facilities, we suggest considering the following adaptation options.

**Figure 8-1:** Process to Determine Response to a Climate Change-Related Risk.
8.2 Facility Adaptation

8.2.1 Water Stress & Drought
Water stress and drought pose a risk to businesses through various means: greater water scarcity can lead to regulatory restrictions on water use, higher water costs, interruptions to water-dependent manufacturing processes at facilities or suppliers, and disruptions in energy services. In order to prepare, businesses should measure their direct (site) and indirect (supplier) water consumption, identify key vulnerabilities to water stress, and develop and implement a water management plan. This plan should include measurable goals to reduce this total water use, and disclose its performance through reporting measures.

LMC has already taken significant steps to adapt to increased water risk. Through the use of the World Business Council Global Water Tool and similar assessments, LMC has tracked water consumption at its facilities and determined which are located in regions of highest water stress. As part of its “Go Green” initiative, the company is working to reduce water use from its operations. The company also shares its water conservation strategies through its Water CDP reports. Overall, LMC already has a strong strategy for adapting to potential water risks, and we recommend continuing these efforts, especially as climate change magnifies water stress.

8.2.2 Extreme Temperature
One of the main ways to address extreme heat is to incorporate green design features into LMC’s facilities. Increasing the number of nearby trees, putting in a green or white roof, or installing “cool” pavements in nearby parking lots can help cool buildings during days of high temperature. Implementing these strategies at facilities with a potential risk of extreme heat could help reduce concerns about lost productivity during days of extremely high temperatures.

Another concern related to higher temperatures is greater energy demand for cooling, which in turn can strain nearby utilities. Companies can help reduce this potential risk by pursuing energy efficiency programs. LMC has already developed a strong strategy for reducing the company’s energy use. After setting a goal to reduce facility energy use 25% by 2020, the company has pursued lighting and HVAC upgrades, as well as demand response programs. LMC also has a renewable energy strategy and has installed solar, wind, and biomass technology at select facilities. These projects can be a valuable way to reduce LMC’s vulnerability as strain on energy resources increases.

In addition, a portion of LMC’s business focuses on energy management, energy storage, and renewable energy strategies for the public and private sectors. For example, LMC has recently invested in waste-to-energy generation and technologies to harness energy from the oceans. These types of projects can expand access to new types of energy, and thus it is important for LMC to continue to innovate and invest in these types of projects.

8.2.3 Wildfire
Average losses from wildfires in the United States exceeded $1 billion each year from 2005-2014. The projected increase in wildfires, especially large wildfires, is expected to result in even greater losses in the United States. In addition, large wildfires that burn for long periods of time can result in lost work hours and lower revenues for businesses.
To minimize impacts from wildfire at the facility level, LMC should be mindful of the vegetation outside its facilities. Nearby vegetation should have a low flammability and be appropriately spaced from both the building and other vegetation to avoid adding fuel to the wildfires. Creating fireproof gaps between the building and vegetated areas, such as parking lots or roadways, can also help prevent the spread of wildfires. As for the building itself, fire-resistant building materials, such as concrete or brick, can further reduce potential infrastructure damage.

For facilities that are located near a forest area, LMC can coordinate with local fire agencies or the U.S. Forest Service, if applicable, regarding forest management. It is important that forests are actively managed through strategies such as forest thinning, removal of fuel loads, and prescribed burns.

Lastly, to reduce the potential for large wildfires, one of the most important steps to take is to slow global warming through GHG emissions reduction. LMC has already taken steps to reduce GHG emissions by increasing energy efficiency, Leadership in Energy and Environmental Design (LEED) certified buildings, and renewable energy procurement. We recommend continuing these efforts and also considering what else could be done to reduce GHGs from LMC operations and supply chain.

### 8.2.4 Flooding

Stretching from the Northeast to the Southern region of the United States, there are several LMC facilities that could be affected by flooding. The most effective adaptation strategy to prevent loss from flooding at these sites would be to relocate facilities out of flood plains and away from the coast. However, except in extreme situations, relocating facilities is not a viable solution. Below we discuss some alternative adaptation strategies.

There are several levels at which a business can adapt to flooding: the property level, the city level, and the regional level. Property level adaptation can come from increasing the number of pervious surfaces on premise, eliminating any crawl spaces or areas that allow for inundation, ensuring floors are above street level, and using waterproof flooring. Additional tactics include installing green roofs and facades and adding a large-scale rain garden to collect and drain runoff. All of these small scale adaptations allow for improved water retention and drainage that will prevent water from pooling and building around the facility.

On a city level, increasing pervious surfaces is an adaptation that could reduce the build-up of rainwater runoff. Other adaptation options include increasing runoff retention through water storage facilities, and eliminating the risk of runoff overflow by separating sewage from water runoff. Another option is to build flood plains around areas with higher risk of flooding: in dry periods this area would provide a functional public space, but in times with large amounts of rainfall and water accumulation the area would be able to absorb the impact and help prevent infrastructure damage.

Finally, at the regional level, the most important adaptation strategy will be planning. With risks of supply chain disruption and lost business days increasing due to climate change, extensive
regional planning that assesses flood evacuation routes and insurance plans can help build resiliency for a company in a region with increased flood risk.

8.2.5 Sea Level Rise
Historically, our coastlines have been altered so society can build and occupy the coasts. This has meant that wetland areas have been dredged and filled to create higher elevation land that is suitable for coastal infrastructure, and dunes have been depleted and destroyed to allow for better viewsheds or more building area. Sediment transport has also been interrupted to prevent natural beach erosion, and barrier islands have been inhabited for their ocean proximity. Each of these modifications worsens the potential effects of sea level rise, which include coastal flooding, higher storm surge, and saltwater intrusion. One of the most extensive plans in a highly urban area to try to lessen these risks has been the NYC Climate Change Adaptation Plan.

One of the plan’s strategies for adapting to sea level rise is to increase coastal edge elevations. This can be done by building bulkheads and using beach nourishment. Bulkheads are permanent structures that retain sediment and prevent erosion of the coastal land, particularly where there is existing coastal infrastructure. A second option is beach nourishment, which takes offshore sediment and puts it back on the beach, thereby allowing for better beach protection from higher tides and incoming storm surges. This storm surge protection can also come from living shorelines that provide a natural barrier. An additional option mentioned in the plan is coastal restructuring. This technique involves building structures like bulkheads and storm surge gates, along with restoring natural wetlands and beach defenses where feasible, to provide mixed protection from the different impacts of sea level rise.

Sea level rise is a potential risk that is difficult for a single business, no matter how large, to adapt to. LMC may be able to apply these adaptation strategies to the facilities close to the coast, in Florida and Virginia, but any long-term solutions are certain to require collaboration with city and state government agencies.

8.3 Supplier Adaptation

LMC faces potential climate change-related risks not only at its facilities, but also across its supply chain. Although LMC has less control over the actions of its suppliers, there are several techniques the company can use to reduce its supply chain vulnerability.

LMC has already made a commitment to Sustainable Supply Chain Management. The company explains: “We define Sustainable Supply Chain Management (SSCM) as ‘management of our supply base to drive affordability and innovation through social responsibility and environmental stewardship.’ The objective of SSCM is to ensure alignment of our supply base’s social, ethical, environmental, safety and health responsibilities with Lockheed Martin’s sustainability commitments.” Furthermore, the company explains, “Lockheed Martin builds sustainable supplier capacity by partnering with our supply chain to reduce adverse environmental impacts, to promote human rights, health, safety, and ethical behavior, and to enable responsible supplier growth and raise standards.” For example, LMC conducts supplier webinars on sustainability topics, and issues a survey to targeted suppliers to identify sustainability risks, including climate
change- and water-related risks, that LMC may face along its supply chain. While these activities can help mitigate certain climate change-related risks, such as water stress, drought, and extreme heat, they tend not to address other potential risks, such as floods, sea level rise, or wildfire.

For these latter three potential risks, one of the greatest threats to LMC is damage to its suppliers’ facilities or interruptions to delivery routes. When selecting new suppliers, LMC should assure that suppliers in these regions are adequately assessing such risks. Choosing suppliers in a diverse set of locations can also help lower the chance of significant disruption. In addition to monitoring new suppliers for these vulnerabilities, LMC should be aware of the growing concern regarding changes in access to key biological feedstocks, such as bio-based fuels, as temperatures rise and water scarcity increases.

As for managing potential risks with existing suppliers, a 2012 report by the World Economic Forum and Accenture suggests the best way is for businesses, government agencies, and suppliers to collaborate by sharing information on supply chain risks and best practices for mitigating them. Some businesses are already partaking in this process, such as those who are members of the Supply Chain Risk Management Council. Sample members include Boeing, Cisco, Zurich Insurance, Rand Corporation, and FedEx. A second technique the report suggests is for businesses to use scenario planning to help prepare for possible disruptions. As the potential risks to supply chains grow, especially when accounting for international suppliers, these steps may help improve resiliency.

8.4 Summary

A more detailed assessment of the potential risks across LMC’s facilities and supply chain would be necessary to determine which adaptation efforts are best to pursue at specific LMC facilities and supplier locations. The company would need to weigh costs from the potential risks versus costs of developing and implementing an adaptation plan. LMC would also need to weigh the tradeoffs that each adaptation option involves. For instance, while installing permeable pavement at LMC’s sites would reduce potential flooding risk, doing so would also involve a financial cost: this cost would only be justified if damage to LMC facilities from future floods exceeds this investment cost. A future project could involve a further analysis of current resiliency plans at LMC, as well as an in-depth analysis of adaptation options and their associated benefits and costs.

9 PROJECT LIMITATIONS

Through the previous sections of this report, we highlighted the main risks across each region and provided recommendations for how LMC may use our findings to reduce the company’s vulnerability to climate change. However, there are several limitations in using our data analysis to assess current and projected risks for LMC’s facilities and supplier locations.

The first of these limitations is that our assessment of current risk relies on historical data. Therefore, the validity of these scores depends on whether past or recent climate trends truly
reflect current circumstances. Across years, there can be significant variability in weather events—such as drought, floods, and extreme temperature—especially as natural climate features like El Niño and the Pacific Decadal Oscillation vary. As a result, the use of historical data may provide an inaccurate reflection of current risks.

There are also limitations with our future vulnerability scores. For certain risks, such as drought and flooding, we were unable to find projections for each region. For other risks, such as wildfire and water stress, we were able to find projections for only certain time periods. Even in the case where data was found, the years often did not align exactly with our time frames for short-term (2020-2040) and long-term (2041-2070) risk. This difference in data availability makes it difficult to determine which risks will become most severe in the short- and long-term. A second limitation with the future vulnerability scores is that their validity depends on whether the studies and tools we used (and the models upon which these studies and tools relied) are accurate. All climate models have assumptions and biases, so using other data sources may have led to different conclusions about the future risks across each region.

In addition, the use of a single value (1 through 5) to indicate the current and future risk in a region is another drawback. There are multiple ways to create indices, and different techniques could have led to very different vulnerability scores. In addition, both our current and future vulnerability scores do not take into consideration the relative impact each risk may have on a region. For example, while the South may have more risk of extreme heat compared to the Northeast, the latter may be less equipped for dealing with this risk.

Finally, and perhaps the largest limitation of our study, is that we assessed risk at a regional level. Geography and climate can vary significantly within a region and, thus, the vulnerability score would not be uniform across a given region. For instance, in the Northeast, sea level rise may directly damage facilities or suppliers located on the coast, but not those further inland. Nonetheless, through indirect effects, including damage to energy infrastructure or disruption to transportation routes, sea level rise could still have an effect on inland areas. A vulnerability assessment that looks more closely at the particular locations where LMC has facilities, suppliers, or major transportation routes would be important in helping the company determine which adaptation measures would be most worthwhile.

10  FURTHER RESEARCH TO BE DONE

There are several opportunities to build upon our project to better determine the potential environmental risks LMC faces across its facilities and supply chain. As suggested previously, an evaluation of local risks affecting facilities and suppliers would provide a more precise risk assessment. Topography and local weather strongly affect whether a given environmental risk will affect a particular facility, supplier, or transportation route, yet our region-level assessment does not capture these factors.

A second opportunity would be to assess the financial impact these potential environmental risks could have on LMC. For example, extreme heat could lead to higher energy costs; water scarcity could affect production schedules at facilities or suppliers; and severe flooding could result in facility damage, delayed deliveries, and lost work days. Assessing the economic costs of these
impacts, as well as the probability of their occurrence, would help LMC assess which adaptation efforts are necessary and most cost-effective.

There are also other risks to explore besides the six risks that were included in the vulnerability assessment tool. For instance, regulatory changes—such as the adoption of water restrictions, energy efficiency requirements, or emissions caps—could have a significant impact on LMC’s operations. In addition, climate change may impact energy availability and utility costs. Along with assessing these additional risks, it would be helpful to determine each facility and supplier’s degree of resiliency based on their existing Business Resiliency Plans.

Additionally, a team should examine the environment and climate change-related risks faced by facilities and suppliers outside of the United States; however, some of the data may not be as robust as that in the United States. Looking at potential risks to transportation routes along the supply chain would also be worthwhile. Although we originally hoped to evaluate all of these risks across the Tier 1 and Tier 2 suppliers for a C-130 component, we ultimately had to narrow the project scope to fit the project within our time frame.

Another key approach to mitigate potential economic and brand risks, as well as supply interruption, is to identify climate change-related risks to biological and mineral feedstocks provided by the supply chain. This work is already being undertaken at the Duke Center for Sustainability & Commerce.

Finally, there are many existing resources to help companies more precisely assess their risks. For instance, Verisk Maplecroft provides a Climate Change and Environmental Risk Analytics tool that helps companies determine local-, regional-, and national-level risk. Meanwhile, LogicTools is a software program that helps quantify risk of supply chain disruptions and mitigate impacts from these risks. Furthermore, the Duke Center for Sustainability & Commerce is working with a major analytics company to develop a free-ware analytics tool to examine supply chain risks that expand beyond climate change, such as geopolitics, social risks, and feedstock competition. LMC would gain from identifying and testing different tools to see whether they can provide a more advanced assessment of the potential environment- and climate change-related risks the company may face. Once LMC is able to more accurately determine its potential facility and supply chain risks, the company can better determine which adaptation measures to pursue.

11 CONCLUSIONS

Through this project, we analyzed data for current, short-term, and long-term climate-related risks across nine regions in the United States. We also provided a vulnerability assessment tool that displays these results visually. Through our analysis, we have found several regions where LMC will potentially face high or extreme levels of climate-related risk. Water stress and flooding appear to be two of the most common risks, especially in regions where LMC has a high number of facilities, suppliers, and employees.

We recommend that LMC build upon our findings by doing a deeper dive into the potential risks faced by specific facilities or suppliers in one of the four regions in which LMC currently has the
most facilities and suppliers. We have identified these regions as the South, Southeast, Northeast, and West. This suggestion is strongly echoed in the Center for Climate and Energy Solutions (C2ES)’s 2008 report *Adapting to Climate Change: A Business Approach*, where the authors recommend performing a general assessment (similar to that which we have provided), finding risk hotspots, and then pursuing a more precise risk assessment to determine whether adaptation efforts should be taken in these locations. Once this assessment is complete, we recommend that LMC pursue an additional assessment to determine which adaptation measures are best.

With increasing pressure from customers to improve sustainability, as well as rising business risk from climate change, it is important for LMC to take these steps to improve the resiliency of its facilities and supply chain. The company has already demonstrated its commitment to sustainability through many avenues, but now has a new opportunity to lower potential risks to its infrastructure and disruptions to its supply chain. We hope that the analyses we have provided and the associated vulnerability assessment tool can aid with the first steps in this process.
**12 GLOSSARY**

**C-130 Program:** The C-130 is a military transport aircraft designed and developed by Lockheed Martin. The aircraft is used for various types of missions including personnel transport, special operations, search and rescue, humanitarian relief, and others.  

**Climate Change:** The process in which an area’s typical climate, including its temperature and precipitation patterns, varies over time. Natural factors contribute to climate change, such as alterations in the earth’s orbit, changes in sunlight intensity, and natural fluctuations in greenhouse gas concentrations.

**Drought:** Reduced precipitation over a significant period of time, such as a season or more, which leads to a water shortage.

**Extreme Temperature:** Extreme heat, such as a heat wave, in which temperatures are 10 degrees or higher than the average high temperature in a region, or extreme cold, such as a deep freeze, which is a prolonged period of very cold weather.

**Flood:** An inundation of water onto typically dry land caused by rising water from a stream, river, or other waterway; floods may last for days or weeks, as opposed to flash floods, which generally take place in a short period of time, such as several hours.

**Greenhouse Gas:** Gases present in the atmosphere that absorb heat re-radiated from the earth’s surface. Greenhouse gases such as carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and water vapor are produced naturally but can be emitted through both natural and anthropogenic sources; others such as chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆), are solely man-made.

**Heat Island Effect:** In urban areas, the sun’s heat is absorbed by asphalt, roofs, and pavement and less shade and vegetation is available to keep the area cool; this situation causes an increase in the temperature of the area, known as a “heat island”, which often is much hotter than nearby rural areas.

**Object-oriented Programming:** A programming language model arranged around objects instead of actions and data instead of logic.

**Sea Level Rise:** An increase in the overall volume of ocean water that results from three primary influencers: thermal expansion, the loss of polar ice caps and glaciers, and the melting of ice sheets in Greenland and Antarctica. As the sea level rises, seawater will reach further inland onto previously dry land.

**Sustainability:** Productive harmony of nature and humans, or the practice of using only the resources necessary for survival to allow future generations to exist and thrive. In business, sustainability is generally thought of as three main components: environmental, social, and financial, and to be truly sustainable, all three must be considered.
Supply Chain: The network of companies involved in the raw material supply, production, and distribution of a specific product.  

Tier 1 Supplier: A supplier that has a direct contractual relationship with a company.  

Tier 2 Supplier: A key supplier to the Tier 1 supplier; does not supply directly to the company.  

Visual Basic for Applications: An event-driven object-oriented programming language that is used within Microsoft Office programs, such as Excel.  

Vulnerability Score: A score output from the vulnerability assessment tool for each risk, region, and timeframe. The vulnerability scores were developed in one of two ways: directly from an existing index provided in a dataset, or adapted from ranges in the datasets and modified to fit our tool.  

Wildfire: An unplanned damaging fire in a natural area such as forest, shrubs, grassland, or other vegetation communities.  

Water Stress: The inability to meet human and environmental demands for water. Water stress considers water scarcity, access to water, and water quality.
13 REFERENCES


4 Ibid.

5 Ibid.

6 Ibid.


16 Ibid.

17 Ibid.


21 Ibid.


24 Ibid.

25 Ibid.


27 Ibid.

28 Ibid.

29 Ibid.


31 Ibid.


40 Ibid.


42 Ibid.


Ibid.


Ibid.

Ibid.

Ibid.

Ibid.

Ibid.


Ibid.


Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.

Ibid.


94 Ibid.


99 Ibid.


104 Ibid.


Ibid.


Ibid.


Ibid.


Ibid.


Ibid.


Ibid.

Ibid.

Ibid.

Ibid.


149 Ibíd.


157 Ibíd.


163 Ibíd.


191 Ibid.


193 Ibid.

194 Ibid.


Ibid.


Ibid.


Ibid.


337 Ibid.

338 Ibid.


342 Ibid.

343 Ibid.


346 Ibid.

347 Ibid.


351 Ibid.


353 Ibid.

354 Ibid.


Ibid.


Ibid.

Ibid.


Ibid.

Ibid.


Ibid.

Ibid.

Ibid.

Ibid.

Ibid.
85

370 Ibid.


372 Ibid, pg. 50, 53.

373 Ibid, pg. 53.

374 Ibid. pg. 54.


379 Ibid.


387 Ibid.


392 Ibid.


Ibid.


Ibid.


Ibid.
## Appendix A – Climate Change-Related Risks

<table>
<thead>
<tr>
<th>Type of Risk</th>
<th>Description</th>
<th>Info and Data Needed</th>
</tr>
</thead>
</table>
| **Regulatory** | - Climate change related regulations/ emissions caps  
- Supply chain transparency requirements  
- Water use restrictions | - Current Legislative Activities  
- EPA Laws and Regulations  
- Country specific regulations |
| **Environmental** | - Increased flooding events  
- Rising sea levels/storm surge  
- Extreme weather events  
- Increased temperature  
- Increased frequency of wildfires  
- Water scarcity and increased drought  
- Natural resource scarcity * (including critical raw earth minerals, phosphorus, etc.)  
- Loss of habitat and current biodiversity  
- Changes in pests and disease control  
- Thawing land ice/reduced snowpack | - NOAA sea level rise, temperature, weather events  
- NOAA Climate Data Online Tool  
- USGS water, land use  
- Census data  
- US Forest Service fire mapping  
- USGS rare earth minerals data  
- British Geological Survey World Mineral Production data  
- Component materials  
- Supplier locations and logistics |
| **Geologic** | - Earthquakes | - USGS earthquake mapping |
| **Energy** | - Electricity blackouts  
- Increased demand | - Utilities used by LMC  
- EIA data on price trends  
- EIA data on outages  
- Renewables use at LMC facilities |
| **Social** | - Union strikes  
- Health and safety risks associated with climate change (e.g. extreme heat)  
- Supply chain working conditions* | - History of labor strikes  
- US Dept. of Labor Work Stoppages Data  
- NOAA data on temperature  
- Component materials  
- Supplier locations and logistics |
| **Financial** | - Damage to facilities and infrastructure  
- Constrained production due to resource variability  
- Lost revenue from temporary closure of facility  
- Reputational damage  
- Volatility in energy and commodity prices | - Historical records of LMC facility closures or supply chain disruptions  
- World Bank commodity price data |
| **Resiliency** | - Existence of backup facilities or suppliers  
- Management plans for facilities or supply chain disruptions | - LMC supply chain risk evaluation documents or models  
- LMC plans and protocols  
- Any facility or supplier audit data |
<table>
<thead>
<tr>
<th>Type of Risk</th>
<th>Description</th>
<th>Info and Data Needed</th>
</tr>
</thead>
</table>
| **Transportation** | - Transportation disruptions  
- Degradation of transportation infrastructure | - How inputs are brought to LMC facilities and suppliers  
- Supplier distribution channels  
- USDOT data on infrastructure location and quality |
| **Political* | - Worsened geopolitical situations  
- Terrorism  
- Government corruption  
- Illegal trade  
- Legal risk | - LMC supplier locations and sourcing  
- Political risk and peace indices  
- Government type index |

**Notes:** * Relevant to supply chain only

**References:**

### Appendix B – Environmental Risk Data Sources Reviewed

<table>
<thead>
<tr>
<th>Risk</th>
<th>Data Reviewed</th>
</tr>
</thead>
</table>
- National Drought Mitigation Center: Maps of Current Drought Risk  
- WWF: Water Risk Assessment  
- Climate Change Knowledge Portal: Drought and Flood Predictions  
- WRI: Aqueduct Water Stress Projections  
- University of Nebraska Lincoln: Drought Risk Atlas  
- WBCSD: Water Risk Tool  
- NIDIS: Map and Data Viewer  
- National Weather Service: Climate Prediction Center |
| Extreme Weather                           | - NOAA: Storm Event Data  
- NOAA: Storm Damage  
- World Bank: Climate Change Knowledge Portal  
- EM-DAT: International Disaster Database  
- US EIA: Past Storms in relation to energy infrastructure |
| Flood*                                    | - USGS: Current and Previous Flood Events  
- World Resources Institute: Aqueduct Global Flood Risk Maps  
- FEMA: Flood Maps  
- NOAA: Flood Exposure Map  
- USGS: Coastal Change Hazards Map  
- Cal-Adapt: Wildfire Occurrence Projections for CA |
| Sea Level Rise*                           | - U.S. Dept. of Commerce, NOAA, National Ocean Service: Sea level Rise Viewer  
- Climate Central: Surging Seas Maps and Database  
- U. of Colorado at Boulder: Regional Sea Level Data  
- U.S. Climate Resilience Toolkit: Climate Explorer for Coastal Flood Risk |
| Snow                                      | - NOAA: Palmer Drought Indices  
- IPCC: 5th Assessment Report  
- USGS: Regional Climate Change Viewer  
- NOAA: Storm Events Database  
- NOAA: Snow and Ice data |
| Temperature*                              | - The World Bank Group: Projected Temperature Changes, Climate Change Knowledge Portal  
- NOAA: National Centers for Environmental Information  
- NOAA: National Climatic Data Center  
- Climate International: ClimateData.us  
- Western Regional Climate Center: Western U.S. Historical Summaries  
- USGS: CMIP5 Global Climate Change Viewer  
- Climate Prospectus Team: The American Climate Prospectus Report and Data |
<table>
<thead>
<tr>
<th>Risk</th>
<th>Data Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildfire*</td>
<td>- <strong>USDA</strong>: Wildfire Hazard Potential</td>
</tr>
<tr>
<td></td>
<td>- <strong>USGS</strong>: Federal Fire Occurrence</td>
</tr>
<tr>
<td></td>
<td>- <strong>National Interagency Coordination Center</strong>: Short-Term Predictions of</td>
</tr>
<tr>
<td></td>
<td>Wildfire Risk in US</td>
</tr>
<tr>
<td></td>
<td>- <strong>Atmospheric Environment Publication</strong>: Wildfire and Climate Change</td>
</tr>
<tr>
<td></td>
<td>in Western US</td>
</tr>
<tr>
<td></td>
<td>- <strong>USDA Forest Service</strong>: Annual Fire Detections</td>
</tr>
<tr>
<td></td>
<td>- <strong>Barbero et al. (2015)</strong>: Wildfire Potential and Climate Change</td>
</tr>
</tbody>
</table>

**Notes**: *Included in Duke-LMC Vulnerability Assessment Tool*