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A RISING TIDE FLOATS ALL BOATS, BUT DROWNS INFRASTRUCTURE: THE IMPACT OF SEA-LEVEL RISE ON AMERICA'S MARITIME INFRASTRUCTURE

by

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March 2020

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America's maritime ports provide vital services to the nation's economy and national security functioning as the critical nodes in a transportation network facilitating imports and exports and connecting distribution routes throughout the entire country. Many maritime ports also provide facilities for military operations for all branches of the Departments of Defense and Homeland Security. The homeland security enterprise is primarily focused on counterterrorism. A changing climate brings significant threats across a wide spectrum of vectors. Maritime ports and their supporting infrastructure are at risk of inundation from sea-level rise as a consequence of global climate change. The homeland security enterprise continues to focus on the low probability/high consequence threat of domestic maritime terrorism while a high probability/high consequence event looms just over the horizon. This paper examines the risks, vulnerabilities, costs and consequences posed by the catastrophic threat of sea-level rise—nature's weapon of mass destruction, reviews the dynamics behind recent and current resource allocation, and proposes recommendations for future policy deliberations.

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ABSTRACT

America's maritime ports provide vital services to the nation's economy and national security functioning as the critical nodes in a transportation network facilitating imports and exports and connecting distribution routes throughout the entire country. Many maritime ports also provide facilities for military operations for all branches of the Departments of Defense and Homeland Security. The homeland security enterprise is primarily focused on counterterrorism. A changing climate brings significant threats across a wide spectrum of vectors. Maritime ports and their supporting infrastructure are at risk of inundation from sea-level rise as a consequence of global climate change. The homeland security enterprise continues to focus on the low probability/high consequence threat of domestic maritime terrorism while a high probability/high consequence event looms just over the horizon. This paper examines the risks, vulnerabilities, costs and consequences posed by the catastrophic threat of sea-level rise —nature's weapon of mass destruction, reviews the dynamics behind recent and current resource allocation, and proposes recommendations for future policy deliberations.

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LIST OF ACRONYMS AND ABBREVIATIONS

CBP	Customs and Border Patrol
DHS	Department of Homeland Security
DoD	Department of Defense
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
GenPort	generic port model
IPCC	Intergovernmental Panel on Climate Change
MAGICC	model for the assessment of greenhouse gas–induced climate change
MARAD	Maritime Administration
MSRAM	maritime security risk analysis model
MTS	Maritime Transportation System
NCA	*National Climate Assessment*
NIPP	*National Infrastructure Protection Plan*
NOAA	National Oceanographic and Atmospheric Administration
RCP	representative concentration pathway
SAFE	Security and Accountability for Every (Port Act)
USCG	U.S. Coast Guard

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EXECUTIVE SUMMARY

America's maritime ports play a critical role in supporting domestic and international trade. They facilitate the movement of goods across all economic sectors and contribute trillions of dollars to the gross domestic product. In 2018, U.S. ports directly contributed 2.2 million jobs and $5.4 trillion in economic activity, representing approximately 26 percent of America's gross domestic product.[1] According to the Department of Commerce, "Water transportation moves nearly 70 percent of all U.S. international merchandise trade, including 72 percent of U.S. exports by tonnage."[2] There were over 82,000 vessel port calls at U.S. ports in 2018, requiring access to intermodal transportation systems for approximately 95 percent of U.S. imports and exports by weight.[3] All of this is occurring along the nation's 12,833 miles of coastline.[4] The critical infrastructure that supports the movement of goods is vital to the flow of commerce throughout the nation and provides critical links for international trade.

Maritime port infrastructure includes the resources that support ships and cargo handling, including fixed shore facilities such as terminals, docks, and storage facilities; operational equipment including cranes, power supply, and auxiliary support vessels; and dredged channels and approaches to harbors.[5] In addition, complex intermodal transportation systems are inextricably linked to maritime ports. These connections include rail, road, air infrastructure access to them, and other maritime routes that by necessity are located close to port facilities. Developing infrastructure takes years to plan, design, and build, and infrastructure frequently outlives its planned 30- to 50-year lifespan. This means

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[1] Jon Shumake, "Study Finds U.S. Ports Contributed $5.4 Trillion to GDP," *American Shipper*, March 20, 2019.

[2] "Logistics and Transportation Spotlight," Select USA, accessed September 19, 2019, https://www.selectusa.gov/logistics-and-transportation-industry-united-states.

[3] Bureau of Transportation Statistics, *Transportation Statistics Annual Report 2018* (Washington, DC: Department of Transportation, 2018), https://doi.org/10.21949/1502596.

[4] Benjamin H. Friedman, "Managing Fear: The Politics of Homeland Security," *Political Science Quarterly* 126, no. 1 (Spring 2011): 78, https://www.jstor.org/stable/23056915.

[5] Gena Gibson et al., "Shipping Infrastructure," Technology Brief T17 (Energy Technology Network, June 2011), 1, https://iea-etsap.org/E-TechDS/PDF/T17_Shipping_Infrastructure_v4_final_gs.pdf.

that much of what is being designed and built today will likely remain in place and operational until the end of this century.[6]

Domestic spending on maritime homeland security has focused on prevention and deterrence through robust intelligence collection, information sharing, physical security measures, and a sustained presence through marine, air, and shoreside patrols. The United States spent $2.8 trillion on the global war on terror during the 15 years between 2002 and 2017. Homeland security spending totaled $978.5 billion, or about 35 percent of the total federal funding from 2002 to 2017.[7] Counterterrorism spending averaged about $70 billion annually for the last 10 years.[8]

Earth's climate is undergoing large-scale changes that are measurable, verifiable, and real. Average temperatures are climbing around the world. The year 2019 was the second-warmest year on record, and 2016 was the warmest year ever recorded.[9] With rising global temperatures, sea levels will rise. The *National Climate Assessment* notes that "projections indicate that the frequency, depth, and extent of both high tides and more severe, damaging coastal flooding will increase rapidly in the coming decades. An extreme global sea level rising upwards of 8 feet by 2100 is a possibility."[10]

This examination of the threats, consequences, mitigation applications, and costs associated with sea level rise to U.S. maritime infrastructure in general and at the ports of Norfolk, Virginia, also known as the Port of Virginia, and San Diego, California, specifically. Both ports are similar in that they serve as transportation and transshipment hubs of similar throughput and are home to vital military installations including the largest

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[6] Austin Becker, Ariel Hippe, and Elizabeth L. Mclean, "Cost and Materials Required to Retrofit US Seaports in Response to Sea Level Rise: A Thought Exercise for Climate Response," *Journal of Marine Science and Engineering* 5, no. 44 (2017): 1, https://doi.org/10.3390/jmse5030044.

[7] Laicie Heeley, *Counterterrorism Spending: Protecting America While Promoting Efficiencies and Accountability* (Washington, DC: Stimson Group, May 2018), 11.

[8] Heeley, 12–13.

[9] Rebecca Lindsey and LuAnn Dahlman, "Climate Change: Global Temperature," National Oceanic and Atmospheric Administration, January 16, 2020, https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature; "Global Temperature," National Aeronautics and Space Administration, accessed January 31, 2020, https://climate.nasa.gov/vital-signs/global-temperature.

[10] U.S. Global Change Research Program, *Fourth National Climate Assessment*, vol. 2 (Washington, DC: U.S. Government Printing Office, 2018), 329, https://nca2018.globalchange.gov.

U.S. Navy installations in the world. The Port of Virginia is the fifth-largest container gateway in the United States and contributes $101 billion to the gross domestic product of the region.[11] The Port of San Diego contributes approximately $245.1 billion to the region's GDP.[12]

Given the long lead time necessary to plan, fund, and deliver capital projects and the decades-long lifespan of structures, roads, bridges, and other maritime infrastructure, homeland security planners need to address mitigation goals early to better position resources to mitigate future impacts. Those resources may be severely diminished in the future and will certainly be more competitive to access. The U.S. national debt has eclipsed a record $22 trillion, and it is likely the federal government will be challenged in sustaining spending at the current pace.[13] Competing demands on the federal budget will require cogent arguments and advance planning to counter shifting threats to national security. Increased vulnerabilities to critical infrastructure combined with greater competing demands for diminishing resources require a new approach to risk management and perhaps a refocusing of threat vectors. This project focuses on projections for the year 2100. By intentionally looking forward 80 years, we can match climate-related phenomena with infrastructure life-cycle costs and expected lifespans to portray impacts on specific regions.

Given the probability of a terror attack on U.S. domestic ports vis-à-vis the probability of impacts from sea level rise in a changing climate, this exercise examines the costs and benefits of devoting resources to a low-probability low-consequence threat when a high-probability, high-consequence weapon of mass destruction looms just over the horizon and provides recommendations for new policy prescriptions.

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[11] Erica E. Phillips, "At the Water's Edge, Seaports Are Slowly Bracing for Rising Ocean Levels," *Wall Street Journal*, February 11, 2019, https://www.wsj.com/articles/at-the-waters-edge-seaports-are-slowly-bracing-for-rising-ocean-levels-11549882801.

[12] "Gross Domestic Product," Bureau of Economic Analysis, accessed March 2, 2020, https://www.bea.gov/data/gdp/gross-domestic-product.

[13] Bill Chappell, "U.S. National Debt Hits Record $22 Trillion," National Public Radio, February 13, 2019, https://www.npr.org/2019/02/13/694199256/u-s-national-debt-hits-22-trillion-a-new-record-thats-predicted-to-fall.

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I. INTRODUCTION

America's maritime ports play a critical role in supporting domestic and international trade. They facilitate the movement of goods across all economic sectors and contribute trillions of dollars to the gross domestic product. In 2018, U.S. ports directly contributed 2.2 million jobs and $5.4 trillion in economic activity, representing approximately 26 percent of America's gross domestic product.[1] According to the Department of Commerce, "Water transportation moves nearly 70 percent of all U.S. international merchandise trade, including 72 percent of U.S. exports by tonnage."[2] There were over 82,000 vessel port calls in U.S. ports in 2018, requiring access to intermodal transportation systems for approximately 95 percent of U.S. imports and exports by weight.[3] All of this is occurring along the nation's 12,833 miles of coastline.[4] The critical infrastructure that supports the movement of goods is vital to the flow of commerce throughout the nation and provides critical links for international trade.

The impacts of climate change are projected to be substantive in both social and economic terms. Scenarios associated with significant changes in the climate worldwide include altered human migration patterns, dramatic impacts on agriculture and crop production practices, global sea level rise, and increasingly varied and potentially devastating weather extremes. While findings are subject to debate, the overwhelming consensus in the scientific community is that climate change is a significant threat that will bring dramatic changes to the environment in the decades to come. Recent estimates project that sea levels will rise one to two meters by the year 2100.[5] For this thesis, we will not

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[1] Jon Shumake, "Study Finds U.S. Ports Contributed $5.4 Trillion to GDP," *American Shipper*, March 20, 2019.

[2] "Logistics and Transportation Spotlight," Select USA, accessed September 19, 2019, https://www.selectusa.gov/logistics-and-transportation-industry-united-states.

[3] Bureau of Transportation Statistics, *Transportation Statistics Annual Report 2018* (Washington, DC: Department of Transportation, 2018), https://doi.org/10.21949/1502596.

[4] Benjamin H. Friedman, "Managing Fear: The Politics of Homeland Security," *Political Science Quarterly* 126, no. 1 (Spring 2011): 78, https://www.jstor.org/stable/23056915.

[5] John A. Church and Neil J. White, "Sea-Level Rise from the Late 19th to the Early 21st Century," *Surveys in Geophysics* 32, no. 4–5 (September 2011): 585–602, https://doi.org/10.1007/s10712-011-9119-1.

argue whether climate change will impact the environment but rather accept as fact that the impact of a changing climate will result in a wide array of significant consequences, particularly substantial sea level rise through the rest of this century and beyond. With this as a backdrop, the primary variable will be the range of impacts to maritime infrastructure and accompanying losses to local and national economies and costs associated with preventing and mitigating damage.

A changing climate and the associated sea level rise will have a devastating effect on maritime ports and infrastructure. Rising sea levels present a severe threat to vital infrastructure, which poses significant challenges to the U.S. economy and, by association, national security. Infrastructure will be threatened in many ways, including the increased risk of flooding, erosion, storms, and coastal subsidence. In addition to waterfront facilities such as docks, piers, and gantry cranes, complex intermodal transportation systems are inextricably linked to maritime ports. These connections include rail, road, air infrastructure access to them, and other maritime routes that by necessity are located close to port facilities. Creating infrastructure takes years to plan, design, and build, and infrastructure frequently outlives its planned 30- to 50-year lifespan. This means that much of what is being designed and built today will likely remain in place and operational until the end of this century.[6]

Given the long lead time necessary to plan, fund, and deliver capital projects and the decades-long lifespan of structures, roads, bridges, and other maritime infrastructure, homeland security planners need to address mitigation goals early to better position resources to mitigate future impacts. Those resources may be severely diminished in the future and will certainly be more competitive to access. The U.S. national debt has eclipsed a record $22 trillion, and it is likely the federal government will be challenged in sustaining spending at the current pace.[7] Competing demands on the federal budget will require

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[6] Austin Becker, Ariel Hippe, and Elizabeth L. Mclean, "Cost and Materials Required to Retrofit US Seaports in Response to Sea Level Rise: A Thought Exercise for Climate Response," *Journal of Marine Science and Engineering* 5, no. 44 (2017): 1, https://doi.org/10.3390/jmse5030044.

[7] Bill Chappell, "U.S. National Debt Hits Record $22 Trillion," National Public Radio, February 13, 2019, https://www.npr.org/2019/02/13/694199256/u-s-national-debt-hits-22-trillion-a-new-record-thats-predicted-to-fall.

cogent arguments and advance planning to counter shifting threats to national security. Increased vulnerabilities to critical infrastructure combined with greater competing demands for diminishing resources require a new approach to risk management and perhaps a refocusing of threat vectors.

From a national security perspective, significant threats to an economic sector that accounts for 25 percent of the U.S. gross domestic product represent a clarion call for action. Overt threats to the airline industry, public spaces, or schools would certainly draw a determined effort by homeland security practitioners to prevent or mitigate losses in those sectors. Threats to maritime port infrastructure pose long-term consequences to the health and well-being of the U.S. economy. Rebuilding, relocating, or reinforcing vast amounts of substantial and costly infrastructure will require detailed long-term planning; will involve federal, state, and local governments as well as significant private-sector investment and partnerships; and could prove extremely expensive. An overt threat of a weapon of mass destruction to any sector would undoubtedly draw significant attention and resources to mitigate the impacts. This thesis examines the threats and vulnerabilities of America's maritime port infrastructure with regard to rising sea levels.

Predictive models suggest that America's ports and waterways will be severely threatened as sea levels rise. Additional threats include the increased risk of more potent and frequent weather systems including hurricanes and associated storm surges. Infrastructure in maritime ports is, out of necessity, generally exposed to the oceans and developed with inherent levels of risk. Maritime infrastructure components share a common denominator in that they play a key role in supporting maritime transportation and, in doing so, are physically located on, over, or adjacent to waterways. As such, they are exposed to a variety of large-scale risks and vulnerabilities that planners address through a number of channels, including the *National Infrastructure Protection Plan* (*NIPP*).[8]

[8] Department of Homeland Security, *NIPP 2013: Partnering for Critical Infrastructure Security and Resilience* (Washington, DC: Department of Homeland Security, 2013), https://www.cisa.gov/sites/default/files/publications/national-infrastructure-protection-plan-2013-508.pdf.

The tenets of *NIPP* are to "identify, deter, detect, disrupt, and prepare for threats and hazards to the Nation's critical infrastructure; reduce vulnerabilities of critical assets, systems, and networks; and mitigate the potential consequences to critical infrastructure of incidents or adverse events that do occur."[9] The primary focus of maritime homeland security efforts has been on preventing acts of terror at U.S. ports and waterways. Billions of dollars have been spent on countering terrorism in maritime ports by government agencies and the private sector since the passage of the Security and Accountability for Every (SAFE) Port Act of 2006.[10] There have been no successful terror attacks on U.S. domestic ports in the past 20 years, and nothing significant since Puerto Rican separatists caused minor damage to facilities in San Juan and Miami in 1974.[11] There have been relatively few reports in the unclassified realm of intended or thwarted attacks in the intervening years. Worldwide, there were only two reported terrorist attacks on port facilities from 2001 to 2019.[12]

Preventing terrorist attacks has been the primary driver of maritime port protection policy, resource allocation, and comprehensive planning for years following the 9/11 attacks. Untold dollars and labor have been spent on enhancing intelligence collection, sharing data and analyses, increasing capability and capacity, and by extent, hardening and protecting U.S. maritime port infrastructure. To date, there have been no successful attacks on domestic maritime ports, and there has been no indication of current or increasing threats of terrorist attacks. Given the probability of a terror attack on U.S. domestic ports vis-à-vis the probability of impacts from a changing climate, it is important to examine the costs and benefits of devoting resources to a low-probability, high-consequence threat when a formidable high-probability, high-consequence menace looms just over the horizon. A comprehensive review of the projected impacts of sea level rise due to climate

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[9] Department of Homeland Security, 1.

[10] Security and Accountability for Every Port Act of 2006, Pub. L. No. 109–347, 120 Stat. 1884 (2006), https://www.congress.gov/109/plaws/publ347/PLAW-109publ347.pdf.

[11] National Consortium for the Study of Terrorism and Responses to Terrorism, "Jihadist Terrorist Plots in the United States" (College Park: University of Maryland, 2017), 4.

[12] James Wilkes and Gray Page, "Rethinking Maritime Security," Safety 4 Sea, October 25, 2017, https://safety4sea.com/rethinking-maritime-security-2/.

change on maritime critical infrastructure is urgently needed, and a pathway for mitigating these threats should be an integral element of future homeland security doctrine. Key to this analysis is the question of resource allocation: does the value of resources allocated to current priorities effectively correspond with current and future threats? A lack of attention by the homeland security enterprise in preventing and mitigating the cumulative effects of a changing climate and sea level rise on our maritime infrastructure could have drastic negative impacts on the continued economic health and national security of the United States now and well into the future.

A. RESEARCH QUESTIONS

What are the risks to U.S. maritime infrastructure associated with sea level rise caused by a changing climate? This thesis reviews the threats, consequences, and mitigation applications and associated costs to the United States in general and in the ports of Norfolk, Virginia, also known as the Port of Virginia, and San Diego, California. Both ports are similar in that they serve as transportation and transshipment hubs of similar throughput and are home to vital military installations of significant strategic importance. What are the costs and benefits of focusing on counterterrorism versus sea level rise? What are the risks and consequences of continuing on this pathway? Is it time to recalibrate our thinking and refocus our resources to mitigate the impacts of sea level rise before it becomes nature's ultimate weapon of mass destruction?

B. RESEARCH DESIGN

Several issues were addressed in an attempt to answer the research questions. A comprehensive literature review provided insight into the process of shaping current policies and the challenges of forecasting an unknown future. Key to this effort were recent studies conducted in each of the two ports. Both regions had undertaken detailed studies of the impacts of a changing climate in general and sea level rise in particular on their respective maritime infrastructure. A comparative analysis of the findings provided great insight into their approaches, assumptions, challenges, and plans for the future. Included in the findings were costs associated with potential losses. This served as a baseline to

conduct a rudimentary cost–benefit analysis for current and future resource allocation policies.

An analysis of current drivers of resource allocation for U.S. maritime critical infrastructure examined whether current policy decisions have been effective and fact-based and whether they have provided an acceptable return on investment. It also considered other potentially greater challenges and risks with potentially greater consequences that might not be adequately addressed or might even be ignored. This thesis presents a policy options analysis to develop and outline potential policy directions and gauge their efficacy in addressing the future challenges to maritime critical infrastructure protection in the homeland security enterprise writ large and in two key maritime ports in particular. In addition, a review of technical and engineering mitigation strategies is included. Costs associated with potential infrastructure losses have played a key role in determining actions in response.

A multi-dimensional approach to this multi-faceted problem included a detailed descriptive analysis, current policy and budget review, cost estimates, scientific projections, and an exploration of prescriptive policy and technical options. The approach included a wide-aperture perspective for U.S. homeland security and a narrower focus on the Ports of Virginia and San Diego. This also included a review of practices, policies, and technological innovations for potential applications in U.S. ports and waterways.

Defining maritime infrastructure was necessary as a reference throughout the research. This definition was critical to researching past, present, and future policy decisions and resource allocations. This definition as a common denominator applied to all phases throughout the research ensures consistent comparisons and vernacular. Current literature highlighting valuations of the maritime infrastructure in Norfolk and San Diego in terms of potential losses from rising sea levels was evaluated with additional tools. Determining value was a critical element of the research and a key determinant in mitigation strategies. This step required an inventory of port infrastructure, which included maritime port facilities as well as intermodal systems that could be affected, including railheads, airports, and highways located in the impact zones.

A detailed review of climate change predictions and associated projections was included to provide a clear understanding of the causes and effects on global ecosystems. An assessment of the fundamental approaches used to make projections was essential to support the logic and reasoning underlying predictions and scoping the prescriptions. This thesis has included global climate change and sea level rise predictions as well as regional and local projections for the two ports in the study. Key to this understanding were several foundational reports. The first is the United Nations Intergovernmental Panel on Climate Change (IPCC)'s report on the ocean, cryosphere, and climate change published in 2019.[13] The IPCC report provided a detailed analysis on the causes and long-term implications of a changing climate and served as the basis for specific predictions on rising sea levels, among many others. The second is the *Fourth National Climate Assessment* (*NCA*) produced by the U.S. Global Change Research Program, a consortium of government and academic researchers, scientists, economists, and forecasters.[14] The assessment reviewed the science examining climate change; detailed forecasts of change in a wide variety of areas, including weather patterns and sea levels; and assessed the sociological, environmental, and economic impacts in the United States.

Sea level inundation tools provided by the National Oceanic and Atmospheric Administration (NOAA) identified specific areas within geographic areas that would be inundated given variable sea level rise projections.[15] The predictive tools provided forecasts on the extent of potential inundation and afforded a model for calculating sea level rise worldwide and the specific impacts on the Ports of Norfolk and San Diego. With this information, those infrastructure components potentially affected by rising sea levels were identified and reviewed within the confines of the individual port projections within the respective local studies. An open-source website managed by the Department of Homeland Security (DHS) that maintains homeland infrastructure foundation-level data

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[13] Hans-Otto Pörtner et al., *Special Report on the Ocean and Cryosphere in a Changing Climate* (New York: United Nations, 2019), https://www.ipcc.ch/srocc/.

[14] U.S. Global Change Research Program, *Fourth National Climate Assessment*, vol. 2 (Washington, DC: U.S. Government Printing Office, 2018), https://nca2018.globalchange.gov.

[15] "Sea Level Rise Viewer," National Oceanic and Atmospheric Administration, accessed September 19, 2019, https://coast.noaa.gov/digitalcoast/tools/slr.html.

helped to define and identify infrastructure across multiple sectors, including maritime and transportation, and could be used to "support community preparedness, resiliency, research, and more."[16] This information, coupled with NOAA's sea level rise viewer provided a comprehensive picture of the specific impacts of rising sea levels on the two ports of study. These appraisals provided insight into local planners' processes, focus, and considerations when facing an uncertain future.

Developing options and estimated costs to replace or rebuild based on sea level projections for 2100 help to determine the best decision pathways for recommendations. Potential courses of action include maintaining the status quo with no response, planning for some minimal sea level rise, or shifting the primary focus to mitigating the impact of climate change. Inherent in these options are projections for threats and costs associated with rising sea levels and an analysis of probability, risk, and consequences. Policy options were developed, analyzed, and compared. The research was challenged by a lack of concrete data, as Becker et al. note that "few assessments of regional port adaptation to climate change have been conducted, largely due to a lack of comprehensive physical data."[17]

A review of the current focus of homeland security policies, regulations, and activities provided insight into resource allocation, policy decisions, and current and future trends. A review of terrorist threats to U.S. ports and waterways was conducted and compared with the risk, probability, and consequences of rising sea levels. An in-depth review of historical and projected terrorist threats along with a similar review of the impacts of rising sea levels on maritime port infrastructure was used to shape recommendations. The threats and consequences were applied to a simplified cost–benefit analysis to determine the highest risk and greatest return in developing recommendations for future action. Additional analysis examining the underlying predilections for prioritizing counterterrorism at U.S. ports accompanied the review of threats and vulnerabilities. Understanding why decisions have been made—what influencers,

[16] "HIFLD Open Data," Department of Homeland Security, accessed September 19, 2019, https://hifld-geoplatform.opendata.arcgis.com/.

[17] Becker, Hippe, and Mclean, "Cost and Materials Required to Retrofit US Seaports," 13.

stakeholders, and the public factor into decision making—plays an important role in understanding the process and explaining the logic behind strategic decisions. Knowing these influences and biases will help future policymakers prepare for better-educated resource allocation decisions.

Understanding the science behind projections for global sea level rise was vital to helping determine the impacts of sea level rise on the ports of Virginia and San Diego in terms of threatened maritime infrastructure. Local and regional variances to global mean sea level rise predictions were explored and provided for both locations. These are important considerations in future planning efforts as global predictions are generally envisioned as the mean expected sea level rise. Local variances will occur due to vertical land movement or subsidence, changes in ocean currents, and adaptation and mitigation strategies that are employed. A critical review of self-assessments and studies of the impacts of sea level rise provided insight into political, social, and economic perspectives in each region. Although sea level rise will vary based on regional characteristics, each location faces similar future challenges and share common issues regarding adaptation and mitigation. The similarities and differences are addressed in this thesis, which provides insight into varied approaches and underscores the need for federal national standardized approaches, policies, and benchmarks.

The conclusions and recommendations highlight a potential path forward regarding continued funding and resource allocation decisions. Perhaps it is time to assume that the overall terrorist threat to domestic maritime critical infrastructure has greatly diminished and waned and that a changing climate brings greater risk and consequences through rising sea levels. The analysis of multiple threat vectors and potential outcomes associated with adopting various risk strategies sheds light on hazards, risks, and vulnerabilities. Implied in the research questions are other factors including the costs and benefits, potential courses of action, and the practical and political consequences of the options available. The final chapter reviews best practices, measures their effectiveness, and determines responsibility for their oversight and implementation. Multiple approaches to policies and technical prescriptions are examined to provide recommendations for application to U.S. maritime infrastructure.

Based on the findings, recommendations for policymakers are provided for the way ahead based on recent assessments, strategic planning documents, and projected impacts of sea level rise. Finally, an assessment of the merits, costs, and consequences of pathways is provided, along with a summary of the cost–benefit analyses for each.

II. LITERATURE REVIEW

The intent of this literature review is to examine foundational literature on the critical elements of the thesis. The review defines maritime infrastructure and explores tools for determining vulnerabilities; analyzes current threat vectors and prescriptions to counter them; examines future environmental threats associated with a changing climate; details the cumulative effects of rising sea levels on the homeland security enterprise, with a focus on the ports of Norfolk and San Diego; and discusses policies and activities currently in place and potential focus options.

A. DEFINING MARITIME INFRASTRUCTURE

There are several paths for defining this key ingredient, and the approaches and outcomes are vital in framing the analysis and discussion throughout the course of study. There are numerous methodologies for defining the study set. Ted Lewis defines critical infrastructure as "an infrastructure so vital that its incapacity or destruction would have a debilitating impact on our defense and national security."[18] The nation's economic well-being is inextricably linked to national security. Protecting the engine that drives the economy is a critical element of the *National Security Strategy*, which equates economic security with national security.[19] All efforts to protect key drivers of the nation's economy—the maritime infrastructure in our ports and waterways—are critical to America's national security.

The Marine Transportation System (MTS) is the backbone on which domestic ports and waterways form the body of maritime infrastructure. The U.S. Maritime Administration (MARAD) provides a broad range of the many components of the MTS, and the homeland security enterprise writ large describes the MTS as an affiliation of all elements of maritime port infrastructure, including waterways, port facilities, wharves,

[18] Ted Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation* (Hoboken, NJ: Wiley-Interscience, 2006), 3.

[19] Donald Trump, *National Security Strategy of the United States of America* (Washington, DC: White House, 2017), https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.

docks, and supporting equipment.[20] For this thesis, the MTS is relied on at times to provide a broad reference point, a sort of catchall for the system of systems that encompasses the width and breadth of the U.S. maritime port infrastructure. DHS describes the intrinsic value of and need for protecting these vital assets in the *Maritime Modal Annex*:

> The Nation's economic and military security are fundamentally linked to the health and functionality of the MTS. The security of the MTS is paramount to protecting the Nation and its economy, but it presents daunting and unique challenges to managers of the Maritime Mode. Security of the MTS is intrinsically linked to the security of the maritime domain which contains critical infrastructure and key resources (CI/KR) from many of the other critical infrastructure sectors and Transportation Sector modes. Providing for the security of the MTS depends upon understanding the diverse array of activities in the maritime domain through the transparency of all sector and transportation modal infrastructure and security activities.[21]

Wallischeck has studied the role of the MTS in the interconnected worldwide transportation system and associated global supply chain and examined the impact of past disruptions to the system. He underscores the strategic value of the MTS and its linkages to national security:

> At its core, the MTS is critical to national security and economic stability. The MTS moves the majority of freight arriving and departing from the U.S., and carries the bulk of critical military cargoes around the globe. Consequently, any disruptions of the MTS can put national security at risk, and affect local, regional, national and even global economies. This fact has been borne out by previous maritime disruptions, both natural and manmade.[22]

Wallischeck makes several recommendations that both government agencies and private-sector entities might consider in mitigating future losses. While instructive, his work does

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[20] "Maritime Transportation System (MTS)," Maritime Administration, accessed March 2, 2020, https://www.maritime.dot.gov/outreach/maritime-transportation-system-mts/maritime-transportation-system-mts.

[21] Department of Homeland Security, *Transportation Sector-Specific Plan: Maritime Modal Annex* (Washington, DC: Department of Homeland Security, 2007), 1, https://www.hsdl.org/?abstract&did=474334.

[22] Eric York Wallischeck, *ICS Security in Maritime Transportation: A White Paper Examining the Security and Resiliency of Critical Transportation Infrastructure* (Washington, DC: Department of Transportation, 2013), 1, https://www.hsdl.org/?abstract&did=743534.

not specifically address long-term impacts of sea level rise, focusing primarily on natural disasters and cyberattacks. He does provide useful background, however, on public–private ventures in developing policies to mitigate threats to the MTS.

A full definition and an attempt to value the nation's maritime infrastructure establish a baseline from which to draw inferences. Many sources help to provide direction in defining maritime critical infrastructure. Gibson et al. provide a solid basis for the integrated elements of maritime port infrastructure. They note the economic relevance of the MTS: "Maritime ports handle more freight than all other types of terminals combined."[23] They reference the infrastructure requirements that support all facets of the MTS in three specific categories: port terminals, port operational equipment, and manmade global maritime routes. Port terminal infrastructure includes fixed facilities such as buildings, docks, and power supplies. Port operational equipment includes the vehicles, vessels, and machinery necessary to support cargo handling and ship movement. Global maritime routes include manmade passages that are vital to international trade—e.g., the Panama Canal and the Suez Canal—and trade routes that are shaped by geography and must be maintained to support effective, economical shipping routes.[24] The authors provide detailed and substantive links between global maritime shipping and the vital supporting infrastructure in ports and waterways. They also provide information on life-cycle costs, which are pertinent to further discussions regarding mitigation options.

B. MARITIME HOMELAND SECURITY

The primary focus of maritime homeland security planners has been on efforts to prevent terror attacks in the nation's ports and waterways. It is very challenging to quantify precisely what is spent annually on homeland security in general and on maritime homeland security specifically. The Stimson Group has attempted to quantify annual spending and estimated that the United States spends about $70 billion per year on

[23] Gena Gibson et al., "Shipping Infrastructure," Technology Brief T17 (Energy Technology Network, June 2011), 1, https://iea-etsap.org/E-TechDS/PDF/T17_Shipping_Infrastructure_v4_final_gs.pdf.

[24] Gibson et al., 2.

domestic counterterrorism.[25] Further analysis was conducted by reviewing specific agency budgets and DHS grants to provide more perspectives on funding sources, estimates of totals, and resource allocation. In sum, approximately 14 percent of the federal government's total discretionary funds available were spent on global counterterrorism efforts.[26] Stimson's estimate of counterterrorism-related U.S. spending from 2002 to 2017 does not include foreign contributions to counterterrorism; state and local investments in counterterrorism; some dual-use programs and spending, such as for drones, included in the Department of Defense (DoD)'s base; economic losses and secondary effects associated with the long-term cost of counterterrorism operations and homeland security; and classified counterterrorism spending. Notwithstanding these caveats and additional considerations, Stimson's study group believes that this estimate reflects measurable direct government spending.[27]

Defining current domestic maritime security threats in the unclassified realm falls primarily on budget allocations, federal homeland security grants, and risk models such as the U.S. Coast Guard's maritime security risk analysis model (MSRAM).[28] DHS preparedness grants require threat and vulnerability assessments prior to providing funds for state and local governments and the private sector and includes port security grants among the specific categories of support.[29]

Publications, political speeches, and articles consistently mention the existential threat of terrorism, but few sources actualize the threat or prove there is a significant terrorist threat to U.S. maritime ports. There have been veiled and ambiguous threats by ISIS and Al-Qaeda but very little specifically related to maritime ports. The University of Maryland's National Consortium for the Study of Terrorism and Responses to Terrorism

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[25] Laicie Heeley, *Counterterrorism Spending: Protecting America While Promoting Efficiencies and Accountability* (Washington, DC: Stimson Group, May 2018), 12–13.

[26] Heeley, 5.

[27] Heeley, 11.

[28] Brady Downs, "Maritime Security Risk Analysis Model (MSRAM)," Center for Homeland Defense and Security, June 7, 2008, video, 24:22, https://www.chds.us/ed/items/312.

[29] "DHS Announces Funding Opportunity for Fiscal Year 2019 Preparedness Grants," Department of Homeland Security, April 12, 2019, https://www.dhs.gov/news/2019/04/12/dhs-announces-funding-opportunity-fiscal-year-2019-preparedness-grants.

provides a comprehensive analysis of terrorist incidents in the United States. The database shows no terrorist incidents at U.S. ports since the 1970s.[30] This fact begs the questions of how resource allocation decisions are prioritized in the federal government as well as state and local governments and why follow-on requirements are placed on private-sector operators and enterprises.

C. CLIMATE CHANGE AND SEA LEVEL RISE

Projections on the impacts of a changing climate are varied and encompass a range of scenarios. Several recent studies and subsequent reports provide a scientific assessment of the current situation and serve as a baseline for predicting future impacts. The IPCC, a United Nations–sponsored consortium of worldwide government representatives and researchers, has released a foundational document for gleaning projections of sea level rise. The IPCC published a special report in 2019 that revised predictions from the previous 2016 report based on continued monitoring of temperature changes and ice sheet melting. The report listed higher ranges for sea level rise based on observations and data collected throughout the world.[31] The United States also published a seminal document that leverages the IPCC's findings to provide a more detailed assessment of climate change impacts on the country. The *Fourth NCA* gives localized predictions in great detail.[32] Most regional and local entities base their planning and mitigation efforts on the standards prescribed in these reports.

There are dissenters and skeptics to these reports. For example, Meyer reported in January 2019 that predictions were being revised downward to predict less sea level rise over a longer period.[33] He has noted large variations in the range of predictions and warned there could still be significant impacts in the future, but overall, the picture is not as bleak

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[30] National Consortium for the Study of Terrorism and Responses to Terrorism, "Jihadist Terrorist Plots."

[31] Pörtner et al., *Special Report on the Ocean and Cryosphere*.

[32] U.S. Global Change Research Program, *Fourth National Climate Assessment*.

[33] Robinson Meyer, "A Terrifying Sea-Level Prediction Now Looks Far Less Likely," *The Atlantic*, January 4, 2019, https://www.theatlantic.com/science/archive/2019/01/sea-level-rise-may-not-become-catastrophic-until-after-2100/579478/.

as predicted. A general search on the internet provides a wide range of self-styled specialists and scientists who make similar claims or argue that the oceans cannot rise because there is no room for the water to expand, among other such claims. A prime example appears at a website called Skeptical Science:

> Professor Niklas Mörner, who has been studying sea level for a third of a century, says it is physically impossible for sea level to rise at much above its present rate, and he expects 4–8 inches of sea level rise this century, if anything rather below the rate of increase in the last century. In the 11,400 years since the end of the last Ice Age, sea level has risen at an average of 4 feet/century, though it is now rising much more slowly because very nearly all of the land-based ice that is at low enough latitudes and altitudes to melt has long since gone.[34]

Given the mounting evidence of continued fast-paced global warming, increased confidence in scientific assessments and predictions, and a lack of appetite to reduce greenhouse gas (GHG) emissions, this discourse relies on the assumption that a global mean sea level rise of two meters will occur by 2100.[35] Given this projection, a number of questions need to be answered in the maritime homeland security domain, including general prescriptions to mitigate sea level rise enterprise-wide and at the two specific ports of study. Some entities are already studying the issues. The DoD, for example, acknowledges that much of its coastal and maritime infrastructure is vulnerable to a changing climate, which will affect readiness and financial exposure.[36] The Government Accountability Office (GAO) identified numerous scenarios for climate change in 2014 that evaluate how the DoD has planned to mitigate or address its impacts through planning processes in future development.[37] The GAO provided an update in 2019 that urged DoD

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[34] "How Much Will Sea Levels Rise in the 21st Century?," Skeptical Science, accessed February 18, 2020, https://skepticalscience.com/sea-level-rise-predictions-basic.htm.

[35] David Roberts, "Scientists Have Gotten Predictions of Global Warming Right since the 1970s," Vox, December 4, 2019, https://www.vox.com/energy-and-environment/2019/12/4/20991315/climate-change-prediction-models-accurate; Church and White, "Sea-Level Rise," 585–602.

[36] John A. Hall et al., *Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide* (Alexandria, VA: Strategic Environmental Research and Development Program, April 2016).

[37] Brian J. Lepore, *Climate Change Adaptation: DoD Can Improve Infrastructure Planning and Processes to Better Account for Potential Impacts*, GAO-14-446 (Washington, DC: Government Accountability Office, 2014), https://www.hsdl.org/?view&did=755390.

planners to incorporate climate change projections into capital improvement projects, noting that while the DoD has identified climate change as a threat since 2010, it needs to do more to protect the nearly $1.2 trillion in its real estate portfolio.[38] The Center for Naval Analyses' Military Advisory Board, a group of 16 retired admirals and generals, also provided an assessment of risk in 2007 and updated it in 2014. The board asks, "What additional responses should the national security community take to reduce the risks posed to our nation and to the elements of our National Power (Political, Military, Social, Infrastructure, and Information systems)?"[39]

Linkov and Bridges provide examples of how coastal and inland environments will be affected by sea level rise with a focus on infrastructure. They speak to climate change adaptation and the challenges to homeland security in responding to and planning for the impacts of a warming planet.[40] Carolyn Pumphrey of the Strategic Studies Institute has provided numerous vignettes, strategies, and analyses of policy, public perception, and pathways to address the impacts of a changing climate.[41]

In addition, numerous models are available to determine the risk and costs associated with rising sea levels. Valli Wasp provides keen insight into his approach for mitigating threats from a changing climate, calling for mitigation strategies based on "possibilistic reasoning (anticipating the worst that could happen)" by crafting policies that mitigate long-term, slow-onset consequences of phenomena such as sea level rise.[42] The model for the assessment of greenhouse gas–induced climate change (MAGICC), a sea level model developed by Nauels et al., provides a comprehensive framework for

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[38] Diana Maurer, *DoD Needs to Assess Risk and Provide Guidance on Use of Climate Projections in Installation Master Plans and Facilities Designs*, GAO-19-453 (Washington, DC: Government Accountability Office, June 12, 2019), https://www.gao.gov/assets/700/699679.pdf.

[39] Center for Naval Analyses Military Advisory Board, *National Security and the Accelerating Risks of Climate Change* (Alexandria, VA: Center for Naval Analyses, 2018), https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf.

[40] Igor Linkov and Todd S. Bridges, eds., *Climate: Global Change and Local Adaptation* (Dordrecht, Netherlands: Springer, 2011), https://doi.org/10.1007/978-94-007-1770-1.

[41] Carolyn Pumphrey, ed., *Global Climate Change: National Security Implications* (Carlisle, PA: Strategic Studies Institute, 2008), https://doi.org/10.21236/ADA480687.

[42] Valli A. Wasp, "Will Climate Change the Future of Homeland Security?" (master's thesis, Naval Postgraduate School, 2016), v, https://www.hsdl.org/?abstract&did=796633.

calculating sea level rise and determining impacts utilizing multiple components including thermal expansion, melting ice caps, global glacier contributions, and land water-storage capacities.[43] MAGICC is scalable, and its creators claim it "can be used as a tool to directly investigate the SLR [sea level rise] implications of different mitigation pathways and may also serve as input for regional SLR assessments via component-wise sea level pattern scaling."[44] These will be fully analyzed and synthesized into this thesis to develop risk and mitigation models.

The Department of Energy provides a report on the cumulative impacts of rising sea levels in four specific ports, and the approaches used in the study can be applied to coastal regions or other ports. The ports studied include the mid-Atlantic region and the Pacific Coast, which provide practical applications for the study of Norfolk and San Diego.[45] DHS's Interagency Climate Change Adaptation Task Force provides insight and data on the impacts of climate change and offers measures to mitigate the effects.[46] Also, the RAND Corporation provides an analysis of national security and the accelerating risks of climate change as well as information on risk assessment and planning tools for future mitigation.[47]

D. INFRASTRUCTURE IMPACTS AND IMPLICATIONS

The value of infrastructure at risk to rising sea levels at the Ports of Virginia and San Diego was quantified using models used by the two ports as well as a rudimentary comparison using several modeling tools. The Port of San Diego provided a detailed assessment of potential losses in its 2019 report, *Sea Level Rise Vulnerability & Coastal*

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[43] Alexander Nauels et al., "Synthesizing Long-Term Sea Level Rise Projections—The MAGICC Sea Level Model v2.0," *Geoscientific Model Development* 10, no. 6 (2017): 2495–2524, https://doi.org/10.5194/gmd-10-2495-2017.

[44] Nauels et al., 1.

[45] Department of Energy, *Effect of Sea Level Rise on Energy Infrastructure in Four Major Metropolitan Areas* (Washington, DC: Department of Energy, 2014), https://www.hsdl.org/?view&did=760524.

[46] Climate Change Adaptation Task Force, *Climate Change Adaptation Report* (Washington, DC: Department of Homeland Security, 2010), https://www.hsdl.org/?view&did=4324.

[47] Center for Naval Analyses Military Advisory Board, *Accelerating Risks of Climate Change*.

Resiliency.[48] The Port of Virginia relies heavily on studies by Old Dominion University's Center for Sea Level Rise and others to provide risk and vulnerability assessments.[49] An additional study on the costs of doing nothing in response to sea level rise also contributed to the assessment.[50]

Becker et al. provide a tool for estimating the cost to raise the surfaces of ports to elevate them two meters. The generic port (GenPort) model also calculates the cost of fill materials to raise and reconstruct a port.[51] The paper limits the focus to the top 100 U.S. coastal seaports and finds that the total cost to raise and rebuild infrastructure would be $57–$78 billion in 2012 U.S. dollars.[52] The authors point to a shortcoming of the GenPort tool in that it ignores the connections to roads and rail lines critical to moving commerce in and out of ports. If port facilities and infrastructure are raised, the connections to and likely the roads and rail lines themselves will also need to be raised, dramatically increasing the cost projections. In addition, as noted, variations in regional sea level rise, storm surges, and subsidence all add more variables to the calculus. They do provide, however, a basis for comparing other modeling tools and assumptions on which to base predictions.

E. THE PATH FORWARD

The way ahead includes an analysis of how and why federal planners established terrorism as the greatest threat to maritime port infrastructure. Several authors have approached this ideology from different perspectives with interesting results. Mueller and Stewart provide a detailed analysis of how public opinion is shaped and does shape

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[48] Port of San Diego, *Sea Level Rise Vulnerability Assessment & Coastal Resiliency Report* (San Diego: Port of San Diego, June 2019).

[49] Center for Sea Level Rise, "Center for Sea Level Rise" (Norfolk, VA: Old Dominion University, 2017), https://digitalcommons.odu.edu/cgi/viewcontent.cgi?article=1000&context=hripp_website.

[50] George Van Houtven et al., *Costs of Doing Nothing: Economic Consequences of Not Adapting to Sea Level Rise in the Hampton Roads Region* (Research Triangle Park, NC: RTI International, November 2016), http://resilientvirginia.org/wp-content/uploads/2017/04/20161116-hampton-roads-costs-of-doing-nothing-report.pdf.

[51] Becker, Hippe, and Mclean, "Cost and Materials Required to Retrofit US Seaports," 21.

[52] Becker, Hippe, and Mclean, 1.

counterterrorism policy.[53] They also note the hysteria that accompanied the period after 9/11, which contributed to the overall fear that terror attacks were going to occur with great frequency and widespread destruction, and call for a reasonable analysis and fact-based approach to prioritizing resource allocation.[54]

Friedman examines how the public is influenced by politicians and government agencies and its own personal cognitive biases, claiming that the creation of DHS "increas[ed] the incentives to herald the terrorist threat to the United States."[55] William Clark, writing about the history of risk assessment, notes that medieval Europeans did not fear witches much until they created an inquisition to find them. The inquisition provided its members work, which they justified by promoting the witch threat. Institutionalizing the hunt heightened fear of the danger posed by those they hunted.[56] Friedman also notes,

> Homeland security organizations are not the main promoters of the terrorist threat. That distinction belongs to the military–industrial complex or iron triangle. This is not a conspiracy, but a set of actors in the Pentagon, Congress, think tanks, academia, and the defense industry with a common interest in high military spending and thus in public fear of enemies that justify it, which have been lacking since the Cold War.[57]

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[53] John E. Mueller and Mark G. Stewart, *Public Opinion and Counterterrorism Policy* (Washington, DC: Cato Institute, February 20, 2018), 52, https://www.cato.org/publications/white-paper/public-opinion-counterterrorism-policy.

[54] John E. Mueller and Mark G. Stewart, *Responsible Counterterrorism Policy*, Policy Analysis No. 755 (Washington, DC: Cato Institute, September10, 2014), 20, https://www.cato.org/sites/cato.org/files/pubs/pdf/pa755.pdf.

[55] Friedman, "Managing Fear," 77–106.

[56] Friedman, 92.

[57] Friedman, 94.

III. MARITIME PORT INFRASTRUCTURE: VITAL, VALUABLE, VULNERABLE

Attempting to define infrastructure is fraught with peril. Assigning values to determine relative importance encourages the risk that some components will be ignored, devalued, or arbitrarily provided too much importance. Several definitions are helpful in setting the stage for our analysis. This chapter provides basic descriptions of maritime infrastructure and examines its relevance to strategic imperatives. It also describes in detail the Ports of Virginia and San Diego with a focus on their viability and vulnerabilities.

A. WHAT EXACTLY IS MARITIME INFRASTRUCTURE?

The Marsh report in 1997 defined infrastructure as "a network of independent, mostly privately-owned, man-made systems that function collaboratively and synergistically to produce and distribute a continuous flow of goods and services."[58] The report also defined critical infrastructures as those "so vital that their incapacitation or destruction would have a debilitating impact on defense or economic security."[59]

In 2003, President George Bush described the policies of his administration regarding critical infrastructure protection in the specific terms of protecting

> critical infrastructure and key resources against terrorist acts that could . . . damage the private sector's capability to ensure orderly functioning of the economy and delivery of essential services; have a negative effect on the economy through cascading disruption; or undermine the public's morale and confidence in our national economic and political institutions.[60]

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[58] President's Commission on Critical Infrastructure Protection, "Acting Now to Protect the Future," in *Critical Foundations: Protecting America's Infrastructures* (Washington, DC: President's Commission on Critical Infrastructure Protection, October 1997), 3, https://fas.org/sgp/library/pccip.pdf.

[59] President's Commission on Critical Infrastructure Protection, "Appendix B: Glossary," in *Critical Foundations: Protecting America's Infrastructures* (Washington, DC: President's Commission on Critical Infrastructure Protection, October 1997), B-1, https://fas.org/sgp/library/pccip.pdf.

[60] George W. Bush, *Critical Infrastructure Identification, Prioritization, and Protection*, Homeland Security Presidential Directive 7 (Washington, DC: White House, 2003).

In the heightened awareness of terrorism following the 9/11 attacks, the focus of most planning documents was terrorism. No mention is made of the long-term threats and vulnerabilities associated with climate change.

Defining maritime port infrastructure presents many challenges in terms of breadth and scope. Regional differences play a role as ports throughout the country have unique characteristics depending on their location, history, role, activities, types of waterways, and functionality, among many other dependent and independent variables. The characteristics of each port vary based on geography and the types of cargo it manages. Planning documents and risk assessments include a vast array of integers identifying multiple elements across each port. Gibson et al. provide three primary elements associated with shipping infrastructure. They define shipping infrastructure as a variety of resources that support ships and cargo handling, including fixed shore facilities such as terminals, docks, and storage; operational equipment such as cranes, power supply, and auxiliary support vessels; and dredged channels and approaches to harbors.[61]

Vessel and cargo support is one facet of port infrastructure. Ports must have unfettered access to multiple transportation modes to transship cargo to and from customers for both imports and exports. Cargo in bulk and containers destined for or arriving by vessel need to be moved through ports quickly and efficiently. Moving products through ports is primarily the job of trucks, trains, and planes. The roads, rails, and runways that link port facilities to their customers play a vital role in supporting operations and the economy. Intermodal links are critical support infrastructure that provides linkages to end users. A loss of these essential components would result in congestion, stagnation, and lost revenues. Due to the strong reliance on intermodal connectivity in maritime ports and the potential for impact by sea level rise, this infrastructure is included in this effort. In addition to the three broad elements described above, this thesis includes roads, bridges, railways, airports, buildings, and other supporting components in the definition of maritime port infrastructure and risk and vulnerability assessments.

[61] Gibson et al., "Shipping Infrastructure," 1.

Ports also rely on the transshipment of goods to barges or smaller vessels to keep the flow of commerce unimpeded. In Houston, for example, numerous barges and their accompanying towboats ply Galveston Bay and the connecting intercoastal waterway to move products to more remote locations for further processing, refining, or delivery. San Francisco Bay is the first port south of the Alaskan pipeline terminus in Valdez, Alaska, deep enough to accommodate very large crude carriers. Even this expansive and diverse waterway has its limitations. The oil tankers are often too large to sail inside the bay to reach oil refineries located in Richmond, so the oil must be lightered off the larger ships to smaller vessels that can navigate the shallower channels leading into the Sacramento River where the refineries are located.

All U.S. ports require some degree of upkeep by dredging to keep shipping channels clear and deep enough to accommodate the large deep draft container and bulk carrier ships involved with international trade. Dredging operations are unique in every port, but they are necessary given the industry trends in building larger ships. Shifting tides, outflow from tributaries, and changes in weather patterns all contribute to an increased need for dredging. Fairway channel markers, breakwaters, and jetties are also associated with ports and harbors. These elements are all part of fixed infrastructure that certainly have significant costs associated with their life cycles, but for the purposes of this thesis, they are not included in the maritime infrastructure discussion as the variables and uncertainties are too great across the spectrum of future rising sea levels. For example, changing sea levels will alter the flow of water through ports and the tributaries feeding them, resulting in shifting currents and varied hydrodynamics too consequential and too unknown to attempt to factor in to this effort. The importance and potential impacts are noted and are recommended for future study. Most likely, additional dredging and redefining channels and fairways will have to occur as sea levels rise and will be reactive rather than proactive.

Port-specific documents provide insight into local maritime infrastructure. They include capital investment planning tools as well as vulnerability and risk assessment tools, such as the Coast Guard's MSRAM, which identifies over 17,500 risk assessments of ports

and assets within ports.[62] The *NIPP* sets goals, priorities, and requirements for protecting vital assets.[63] DHS's Homeland Security Information Network provides a platform for sharing data on threats and vulnerabilities. The Federal Emergency Management Agency (FEMA)'s Hazus provides projections for losses from catastrophic events such as flooding and tsunamis. These sources and many more contribute to a body of work that define and prioritize infrastructure writ large for the nation. They assist planners and policy developers in assessing vulnerabilities and allocating resources.

This thesis scopes the definition and limits the focus of the discussion to those infrastructure resources in the United States that are most vulnerable to sea level rise. This definition includes the piers, docks, wharfs, yards, and maintenance facilities; the buildings on them; the ancillary equipment that supports shipping such as cranes, power, sewer, and water systems; and rail, roads, and airports and connections to these intermodal pathways. All these components could be significantly affected and, thus, are included in the calculus. Auxiliary vessels such as tenders, tugs, fuel barges, firefighting and response vessels, and harbor pilot vessels are assumed to be relatively immune from rising seas as they should retain their functionality as long as there is enough water to operate. Ferries that carry passengers and vehicles provide significant contributions to the economies and living conditions in many areas in the country such as Seattle, New York, and San Francisco. Vessels such as these operating in ports and waterways should also remain relatively free from impact by rising sea levels.

In addition to the privately held infrastructure, it is important to note that throughout the country, there are many publicly owned resources in ports and waterways. Several assets fall within this arena. As previously noted, the channels and approaches to harbors and within ports are typically maintained by government assets such as the Army Corps of Engineers. The U.S. Coast Guard maintains buoy systems and other aids to navigation including the vessel traffic systems that coordinate the flow of traffic on the water much like air traffic controllers do for air travel. In many locales, the land in and around ports

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[62] Downs, "Maritime Security Risk Analysis Model."

[63] Department of Homeland Security, *NIPP 2013*.

are federal, state owned, or locally owned by municipalities. Private companies often operate facilities under memoranda of agreement or leases. Oakland, California, for example, owns the land and easements within the port including Oakland International Airport. The Port of Oakland manages the port while private firms lease its facilities to operate their enterprises. They make improvements, such as purchasing and operating multi-million-dollar gantry cranes that move containers in partnership with the port. While these are subtle distinctions in ownership and responsibilities, they do vary from port to port. For the purposes of this exercise, the discussion focuses on the strategic aspects of infrastructure without assigning ownership. The dataset is too large and too varied to attempt to cull individual responsibilities in this venue.

In order to narrow the aperture of this study, two specific ports were selected for a detailed review and comparison. The ports are similar in size and economic and national security importance, yet they are very different in terms of geography and projected impacts from sea level rise. They were specifically selected for these and other reasons. Both the Port of Virginia and the Port of San Diego provide vital throughput for a range of commodities, both are located inside a bay adjacent to the ocean, both fuel regional economies through shipping and jobs, and both host U.S. military installations of strategic importance that house billions of dollars of hardware. All these factors provide strategic value to the nation for both national defense and economic gross domestic product. When factoring in the vital contributions these ports play in these roles, their importance is quite clear. While their vulnerability to sea level rise differs, the impacts are significant, and their risk assessments as well as mitigation and adaptation planning share commonalities worth examining.

B. THE PORT OF VIRGINIA

The Port of Virginia is the fifth-largest container gateway in the United States.[64] The metropolitan area supported by the Port of Virginia contributes $101 billion to the

[64] Erica E. Phillips, "At the Water's Edge, Seaports Are Slowly Bracing for Rising Ocean Levels," *Wall Street Journal*, February 11, 2019, https://www.wsj.com/articles/at-the-waters-edge-seaports-are-slowly-bracing-for-rising-ocean-levels-11549882801.

gross domestic product of the region through a mix of private-sector and government enterprises. Private industry accounts for 72 percent and government spending 28 percent of economic activities.[65] The port is a key ingredient to the region's economic sustainability. Nearly 24 percent of all East Coast trade by weight flows through the Port of Virginia.[66] The approaches and harbor channels are the deepest on the U.S. East Coast. It includes the harbors of Norfolk, Portsmouth, Newport News, the Virginia Inland Port, the Virginia International Gateway, and the Richmond Marine Terminal.

The six components encompass 1,864 acres of terminals and facilities that includes wharves, piers, and parking aprons; 19,900 linear feet of berths; seven miles of on-dock rail; and 22 Suez-class cranes. Each of these cranes costs approximately $11 million.[67] The Port of Virginia reports that 35 percent of its cargo is transported to the port via rail; 62 percent by truck, and the remaining 3 percent via barge.[68] The port estimates that it contributes 397,000 jobs to the region—nearly 10 percent of the state's resident workforce.[69] The Norfolk International Airport is also located within Port of Virginia operating lands and is situated on a low-lying peninsula adjacent to the approximately 18-mile-wide opening of the Chesapeake Bay to the Atlantic Ocean (see Figure 1).

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[65] "Gross Domestic Product," Bureau of Economic Analysis, accessed March 2, 2020, https://www.bea.gov/data/gdp/gross-domestic-product.

[66] Van Houtven et al., "Costs of Doing Nothing" 2–1.

[67] Peter Hildebrandt, "New Gantry Cranes for the Virginia Port Authority," *Wire Rope & News Technology*, August 2019, https://www.wireropenews.com/news-201909-Konecranes.html.

[68] "Home Page," Port of Virginia, accessed March 3, 2020, http://www.portofvirginia.com/.

[69] Roy L. Pearson and K. Scott Swan, *The Fiscal Year 2018 Impacts Virginia Economic Impacts of the Port of Virginia* (Williamsburg, VA: College of William & Mary, November 18, 2019), http://www.portofvirginia.com/wp-content/uploads/2019/11/THE-FISCAL-YEAR-2018-VIRGINIA-ECONOMIC-IMPACTS-OF-THE-PORT-OF-VIRGINIA.pdf.

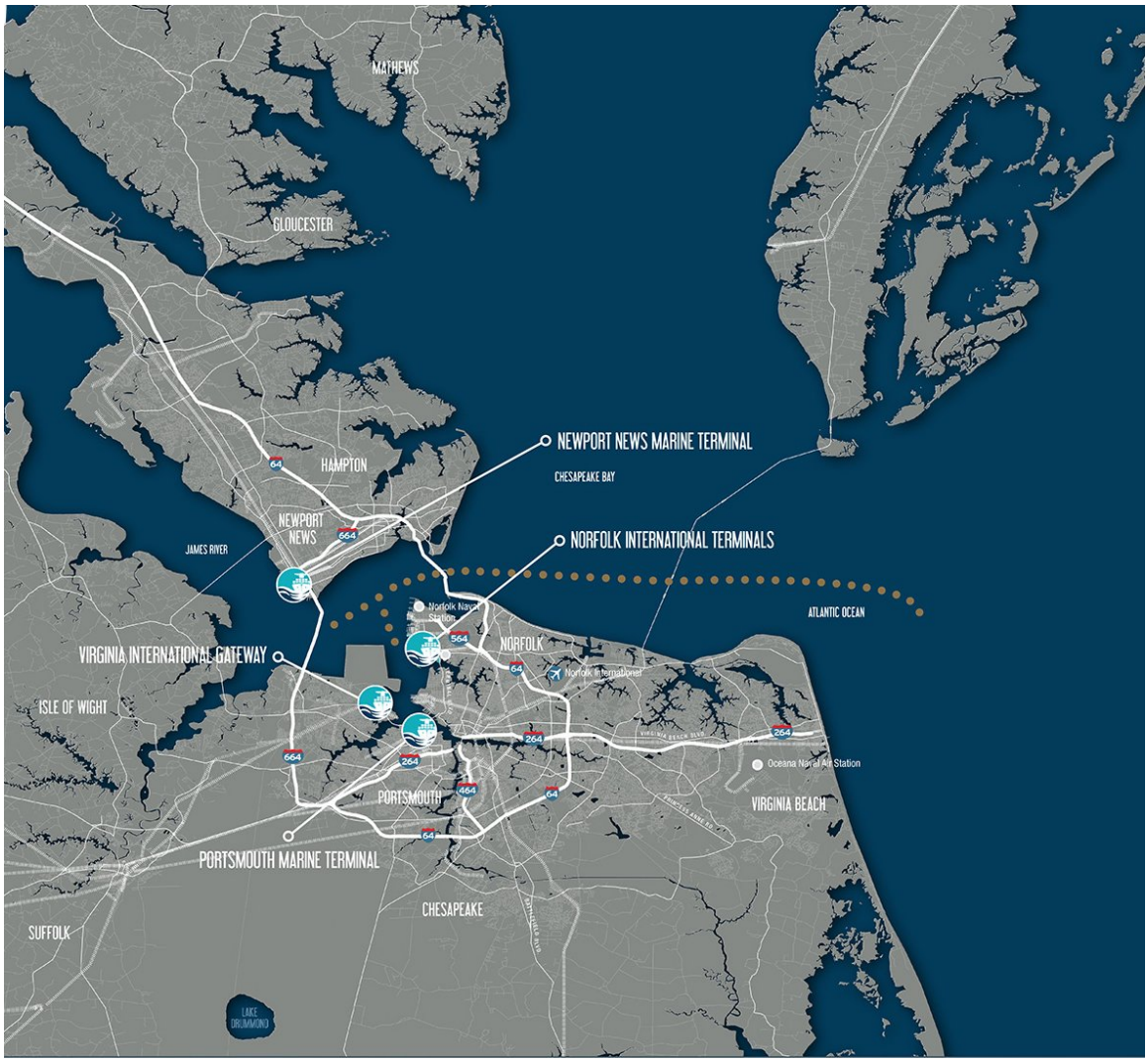

Figure 1. Port of Virginia Marine Terminals in the Hampton Roads Area[70]

One facet of government-owned resources involves established military facilities at the two ports of interest—San Diego, California, and the Port of Virginia in Hampton Roads, Virginia. The military facilities in these two locations comprise the largest installations in the country. The two ports have significant investments in land, improvements, facilities, and other infrastructure, which the military operates and maintains, and are representative of the many other smaller facilities throughout the country. Many individual facilities at the two ports make up the military infrastructure

[70] Source: "Port of Virginia Terminals," Isle of Wight Department of Economic Development, accessed February 24, 2020, https://www.insidetheisle.com/military-installations-major-employers-ports/.

footprint. A brief inventory shows the breadth of infrastructure located on the water or near enough to be at risk from sea level rise. Each port includes a wide variety of military facilities serving a broad array of functions, each of which have unique operating and design characteristics to support the operational units at the facility. The issues the ports face in light of rising sea levels are similar to many others—although at a much different scope and scale. Further chapters contain in-depth analysis of the specific threats to these two ports given rising sea level predictions.

The Port of Virginia is also home to the world's largest naval station and numerous military installations. Military facilities in the region are in Norfolk, Portsmouth, Newport News, Hampton, and Yorktown. Major facilities include Naval Station Norfolk, Fleet Logistics Center Norfolk, Naval Air Station Oceana, Joint Expeditionary Base Little Creek, Norfolk Naval Shipyard, Joint Base Langley-Eustis, Yorktown Naval Weapons Station, and Coast Guard Support Center Portsmouth. Naval Station Norfolk is home to the U.S. Navy's Atlantic Fleet, with approximately 75 ships and over 130 aircraft based there. All of the Atlantic Fleet's six aircraft carriers are homeported in the region.[71] Waterfront facilities include 14 piers stretched along four miles of shoreline. Fleet Logistics Center Norfolk houses a fuel farm and provides fleet logistics and maintenance support throughout the region. Naval Air Station Oceana is home to 18 fleet squadrons including rotary- and fixed-wing aircraft. Joint Expeditionary Base Little Creek provides support services to the 27 ships homeported there and 78 resident and/or supported activities including operational, support, and training facilities. Norfolk Naval Shipyard is the world's largest naval repair facility and includes drydocks, shoreside support, and overhaul facilities. Joint Base Langley-Eustis houses two fighter wings, one surveillance and reconnaissance wing, and two fighter squadrons in addition to numerous support elements. Yorktown Naval Weapons Station is home to 37 tenant commands ranging from munitions storage and handling to training and fleet industrial support and logistics commands. Coast Guard Support Center Portsmouth is the homeport for 10 Coast Guard cutters and numerous

[71] "US Aircraft Carriers Fast Facts," CNN, June 13, 2019, https://www.cnn.com/2013/08/09/us/u-s-aircraft-carriers-fast-facts/index.html.

regional and local support activities.[72] These activities and others are part of a package from the federal government that contributes $28.5 billion to the regional economy. Many, if not most, are closely associated with maritime operations and are located on or near the shoreline (see Figure 2).

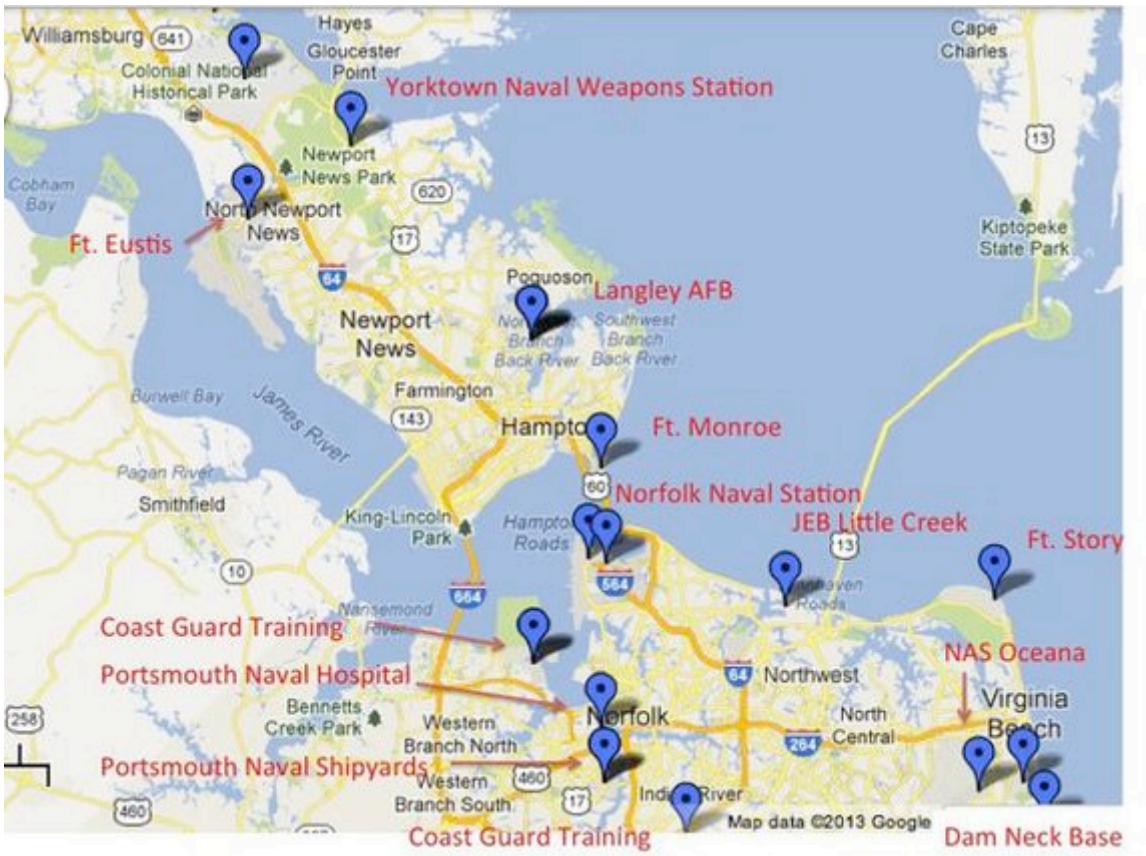

Figure 2. Hampton Roads/Port of Virginia Military Installations[73]

C. THE PORT OF SAN DIEGO

Unlike the Port of Virginia, which spans the far reaches of Chesapeake Bay, the Port of San Diego is condensed in a much smaller bay located behind a narrow barrier peninsula that runs from the southern reaches of San Diego Bay along the Imperial Strand

[72] Cameron A., "Hampton Roads Military Bases," *Military Town Advisor* (blog), November 7, 2016, https://www.militarytownadvisor.com/blog/2016/11/7/202/hampton-roads-military-bases/.

[73] Source: Cameron A.

to the connected and slightly wider North Island where the San Diego Bay meets the Pacific Ocean in a relatively narrow mouth approximately one-half mile wide. San Diego International Airport is also located adjacent to the bay in the inner harbor, and the land it sits on is under the jurisdiction of the Port of San Diego. The gross domestic product contribution for the San Diego region is approximately $245.1 billion. This includes $199 billion in private industry and $46.1 billion in government enterprises.[74] The Port of San Diego includes 47.9 miles of roads, 16.2 miles of rail lines, 233.4 acres of marine terminals, 15 piers, 590 buildings, and 458 storm-water management resources.[75]

Like the Hampton Roads region, San Diego is home to many military installations, most of which are also located on or near the shore. The larger set in San Diego includes Naval Base San Diego, Naval Air Station North Island, Naval Amphibious Base Coronado, Naval Base Point Loma, and Coast Guard Sector San Diego. Included in these commands are the customers they serve and the unique physical aspects of each tenant. The examples that follow are not all-encompassing but were selected to emphasize those facilities containing key maritime infrastructure. Naval Base San Diego is home to over 50 ships and 190 tenant commands and is the primary port for the Pacific Fleet. Naval Air Station North Island is home to two aircraft carriers, 23 aviation squadrons, over 235 aircraft, and 75 additional tenant commands. It is also home to the largest aerospace-industrial complex in the Navy. Naval Amphibious Base Coronado includes 27 tenant commands and is home to Navy SEAL special warfare training and operations on the West Coast. Naval Base Point Loma includes a submarine base with maintenance and drydock facilities, a mine and anti-submarine warfare command, the Fleet Combat Training Center Pacific, and a large fuel farm serving ships and Coast Guard cutters in the Pacific Fleet. U.S. Coast Guard Sector San Diego is home to numerous small Coast Guard cutters and support boats as well as an air station operating helicopters adjacent to the San Diego Airport (see Figure 3).[76]

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[74] Bureau of Economic Analysis, "Gross Domestic Product."

[75] Port of San Diego, *Sea Level Rise Vulnerability Assessment*, 8.

[76] "Military Information," San Diego Tourism Authority, accessed March 3, 2020, https://www.sandiego.org/articles/military/military-information.aspx.

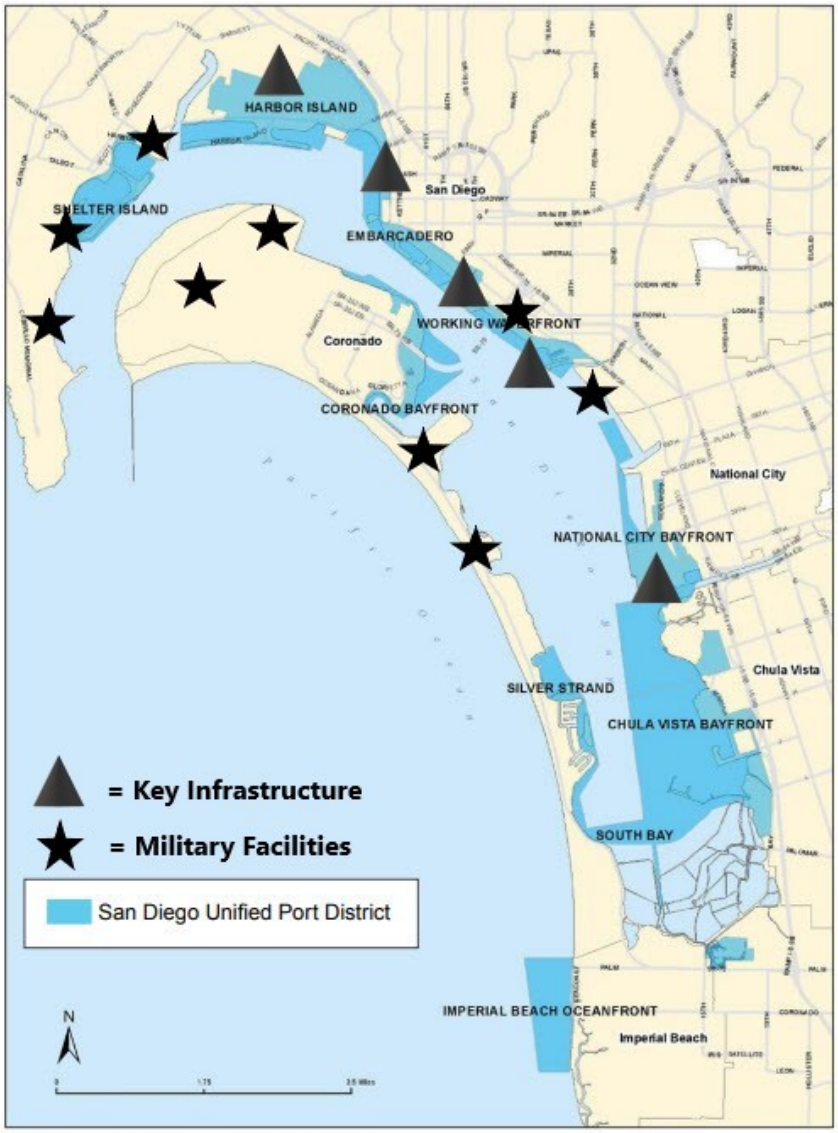

Figure 3. San Diego Harbor[77]

Together, the Hampton Roads and San Diego regions contribute approximately $345 billion annually to the U.S. gross domestic product.[78] Much of this economic input is inextricably linked to the ports in these regions. They are home to trillions of dollars' worth of U.S. military installations, hardware, and infrastructure and support tens of thousands of

[77] Adapted from Port of San Diego, *Sea Level Rise Vulnerability Assessment*, 26. The shaded areas indicate the San Diego Unified Port District; the symbols indicate infrastructure within the harbor area.

[78] Bureau of Economic Analysis, "Gross Domestic Product."

jobs in the public and private sectors. Nearly five million people live in the two regions.[79] The strategic importance of these two areas are closely associated with national defense and the nation's economy. Accurate and realistic vulnerability assessments are crucial to understanding the risks and developing mitigation strategies for all threats. While the threats posed by sea level rise vary by region, consistent approaches by planners will facilitate a better understanding, economies of scale, and a stronger concerted effort to mitigate the impacts of sea level rise.

Lewis describes infrastructure as a series of hubs networked together through interconnected spokes. In this depiction, hubs are the most critical nodes that deserve the highest level of protection.[80] Hubs are considered the most valuable component and, therefore, the node where the most disruption can be seen. This is also the location where investments in protection and prevention can provide the greatest benefits. Lewis notes that not every segment of hubs and spokes can be protected, so resource allocation decisions must be made to protect the most critical components—the hubs.[81] Applying this approach to maritime ports provides valuable insight into valuing and protecting infrastructure through critical node analysis.

If we consider maritime ports and associated infrastructure—such as piers, wharfs, fixed equipment, roads, rail, and airports and other elements described previously—as the primary components of the hub, then the spokes are the roads, railways, rivers, canals, and airways leading to the interior of the country, connecting the ports to customers at inland destinations. It is impossible to protect every mile of roadway or rail line in the country, and many sections of the spokes are not vulnerable to the effects of a changing climate in general and to sea level rise specifically, but the maritime port facilities serving as hubs in the coastal zone are at far greater risk and deserve greater attention to mitigate risk to these valuable assets. Lewis recommends using emergence principles when making resource allocation decisions to reduce or minimize risk. Without conducting complex multivariable

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[79] "Home Page," U.S. Census Bureau, accessed March 3, 2020, https://www.census.gov/en.html.

[80] Lewis, *Critical Infrastructure Protection in Homeland Security*, 2.

[81] Lewis, 15–16.

equations, one could argue that maritime port infrastructure is at the greatest risk from sea level rise by proximity to the oceans, and that in total, the value of these critical nodes—the hubs that serve the entire country—are the most valuable assets at risk from sea level rise.

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IV. MARITIME HOMELAND SECURITY: WHAT ARE WE TRYING TO PREVENT AND WHY?

America's maritime ports and infrastructure are generally defined within the MTS. MARAD promotes a safe and efficient marine transportation system and provides oversight of resources for use in research and development, providing block grants and planning maritime routing among many other responsibilities. MARAD describes the MTS as including "waterways, ports, and land-side connections moving people and goods to and from the water with 25,000 miles of navigable channels and 3,500 marine terminals."[82] Protecting this vast network of interconnected infrastructure falls on multiple federal, state, and local agencies and the owners of private facilities within the ports. The hundreds of thousands of miles of roads, railways, and interstate highways connecting maritime ports to customers are the spokes to the hubs—the ports that serve as critical nodes in the intermodal, international, and domestic marine transportation system. The sheer size of this system and its distribution across the country present many challenges to effectively safeguarding U.S. ports and waterways. No central authority governing security provides oversight of the multiple stakeholders in each port much less on a national basis.[83]

A. MARITIME HOMELAND SECURITY POLICY

Several foundational documents provide broad policies and some regulatory standards for port safety. *The National Strategy for Maritime Security*, published in 2005, acknowledged the multiple jurisdictions and agencies involved in maritime homeland security and addressed the challenges of blending federal, state, and local agencies with the public-private sectors heavily engaged with maritime port infrastructure. The strategy incorporated a series of plans from various federal agencies. These plans focused on maritime domain awareness, global maritime intelligence, a maritime operational threat response plan, international outreach and coordination, maritime infrastructure recovery,

[82] Maritime Administration, "Maritime Transportation System."

[83] Bruce Taylor and Pat Kaufman, "Protecting America's Ports," *National Institute of Justice Journal*, no. 262 (March 2009), https://nij.ojp.gov/topics/articles/protecting-americas-ports.

maritime transportation system and commerce security, and domestic outreach.[84] The SAFE Port Act of 2006 followed along with other directives and policies. The primary focus of these directives was to prevent and respond to the threat deemed most likely to disrupt the MTS: a terrorism incident. In the aftermath of the attacks of 9/11, none of these foundational documents mentions the vulnerability of maritime infrastructure to the threats posed by a changing climate in general or sea level rise specifically.

These policies serve as guides to resource development and drive budgets and resource allocations at every level of government. Determining the costs and budget allocations associated with maritime homeland security is a daunting task, particularly when factoring in budgets at the federal, state, and local levels as well as private-sector participation. This is important because all resource managers need to know whether they are directing scarce assets to the right sectors. In other words, is the value of the investment in counterterrorism worth the opportunity costs of not investing that money elsewhere to prevent other—perhaps higher-risk—contingencies? Policymakers and the public have a difficult if not impossible time determining whether we are spending too little or too much, or even the right amount, on the right vulnerabilities.

B. HOMELAND SECURITY SPENDING

Domestic spending on maritime homeland security has focused on prevention and deterrence through robust intelligence collection, information sharing, physical security measures, and a sustained presence through marine, air, and shoreside patrols. This "cops on the beat" approach is very costly in terms of operations and staffing. It requires fully functional operational assets including the fuel, technologies, and supplies to purchase, operate, and maintain them; command and control systems to sustain situational awareness and operational integrity; highly trained crews proficient in boat or aircraft operations; and technical law enforcement practices and procedures. The cost—spread across multiple federal agencies and state and local governments supporting municipalities and private-sector security measures required by mandates—is staggering if not impossible to quantify.

[84] George W. Bush, *The National Strategy for Maritime Security* (Washington, DC: White House, November 20, 2004), https://georgewbush-whitehouse.archives.gov/homeland/maritime-security.html.

Recent efforts to quantify precise estimates of federal budget allocations for homeland security have been extremely difficult. Examining budget requests and appropriations across multiple agencies, each using its own terminologies and reporting practices and loopholes, adds to the challenge. The Stimson Group conducted an in-depth analysis of government counterterrorism spending. The effort was completed in 2018, and the results help establish a baseline for government-wide spending. The Stimson Group's report determined that the United States spent $2.8 trillion on the global war on terror during the 15 years between 2002 and 2017. This includes four categories: Department of Defense emergency and overseas contingency operations, State Department emergency and overseas contingency operations, foreign aid for counterterrorism, and domestic homeland security spending. Defense spending, which includes funding the war effort in Iraq and Afghanistan, comprised about $1.7 trillion, or 60 percent of the total. Homeland security spending totaled $978.5 billion, or about 35 percent of the total federal funding from 2002 to 2017.[85] While war funding was cyclical depending on imperatives, initiatives, and changing administrations, counterterrorism funding was fairly consistent, averaging about $70 billion annually for the last 10 years.[86]

Viewed from another lens, the group assessed counterterrorism spending as a component of total federal discretionary spending during this time. Total discretionary spending was $18 trillion, and counterterrorism spending accounted for 15 percent of the total. Counterterrorism spending reached a peak of 22 percent but was down to 14 percent of the total in 2017 as war spending was greatly reduced, but the group saw "no indication that counterterrorism spending [was] likely to continue to decline."[87]

The economic impacts of U.S. counterterrorism policies and regulations are significant to both the private sector and state and local governments. The Office of Management and Budget reported in 2008 that homeland security regulations cost the economy between $3.4 billion and $6.9 billion. That was only for major initiatives of over

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[85] Heeley, *Counterterrorism Spending*, 11.

[86] Heeley, 12–13.

[87] Heeley, 5.

$100 million in annual costs, so the actual economic impact most likely trends toward the upper end of the estimate.[88] In the ensuing 12 years, most of those regulations remain in place or have been increased, so the costs associated with homeland security regulations remain significant. The opportunity costs of this spending are also substantial. That is, other valuable programs or initiatives could have benefited from those resources with potentially far more positive influences on society and the economy.

Another methodology to assess domestic homeland security spending is to review the budget of DHS, the primary provider of domestic protection and security. The department's fiscal year 2020 budget was $92.08 billion, according to the Office of Management and Budget.[89] This figure includes a total of $50.47 billion for discretionary spending. The remainder is applied to fixed costs such as salaries and overhead. Within DHS, the U.S. Coast Guard (USCG) and Customs and Border Protection (CBP) are the primary providers of maritime homeland security. Their combined total budgets were $29.4 billion for FY2020—$12 billion for the USCG and $17.4 billion for CBP. Delving further into the labyrinth of federal funding reports, the USCG was allocated $8.2 billion for operations and support and CBP $12.7 billion for the same.[90]

One might determine budget line items for agencies in broad categories and specific activities, but these often have multiple beneficiaries in multi-mission organizations. The USCG, for example, has dedicated security teams for port security, the Marine Safety and Security Teams that are highly trained and outfitted with advanced technologies. Their primary mission is conducting counterterrorism operations to protect local maritime assets, but they may be assigned to cutters on patrol, diverted for search and rescue, or deployed to overseas locations to support contingency operations. The helicopters and fixed-wing aircraft that provide surveillance and command and control are also multi-mission assets that conduct search and rescue and fisheries fishery and pollution patrols, among many

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[88] Friedman, "Managing Fear," 84.

[89] William L. Painter, *Department of Homeland Security Appropriations: FY2020*, CRS Report No. R46113 (Washington, DC: Congressional Research Service, January 21, 2020), https://crsreports.congress.gov.

[90] Painter, 11, 13.

other responsibilities. Counting the costs of resourcing these assets becomes even more challenging when they provide mission support for a variety of tasks. This applies to many of the agencies working to protect the nation's port infrastructure.

DHS provides a range of eight preparedness grants to enhance homeland security at regional and local levels. In announcing the 2019 fiscal year grant program, the department noted,

> The grants provide funding to state, local, tribal, and territorial governments, as well as transportation authorities, nonprofit organizations, and the private sector, to improve the nation's readiness in preventing, protecting against, responding to, recovering from and mitigating terrorist attacks, major disasters, and other emergencies. The grants reflect the Department's focus on funding for programs that address our nation's immediate security needs and ensure public safety in our communities.[91]

DHS provided over $1.7 billion in grants in fiscal year 2019. Guidance accompanying the grant announcement indicates that the grants will be used to focus on the "nation's highest risk areas, including urban areas that face the most significant threats. . . . Consistent with previous grant guidance, dedicated funding is provided for law enforcement and terrorism prevention throughout the country to prepare for, prevent and respond to pre-operational activity and other crimes that are precursors or indicators of terrorist activity."[92] Six of the eight grant categories are germane to this discussion:

> Homeland Security Grant Program (HSGP)—provides more than $1 billion for states and urban areas to prevent, protect against, mitigate, respond to, and recover from acts of terrorism and other threats.
>
> State Homeland Security Program (SHSP)—provides $415 million to support the implementation of risk-driven, capabilities-based State Homeland Security Strategies to address capability targets. States are required to dedicate 25 percent of SHSP funds to law enforcement terrorism prevention activities.
>
> Urban Area Security Initiative (UASI)—provides $590 million to enhance regional preparedness and capabilities in 31 high-threat, high-density areas.

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[91] Department of Homeland Security, "DHS Announces Funding Opportunity."

[92] Department of Homeland Security.

States and Urban Areas are required to dedicate 25 percent of UASI funds to law enforcement terrorism prevention activities.

Operation Stonegarden (OPSG)—provides $90 million to enhance cooperation and coordination among local, tribal, territorial, state, and federal law enforcement agencies to jointly enhance security along the United States land and water borders. Since the enactment of the 9/11 Act, FEMA has required states to ensure that at least 25 percent of the total funds awarded to them under SHSP and UASI are dedicated toward law enforcement terrorism prevention activities (LETPA).

Nonprofit Security Grant Program (NSGP)—provides $60 million to support target hardening and other physical security enhancements for nonprofit organizations that are at high risk of a terrorist attack.

Port Security Grant Program (PSGP)—provides $100 million to help protect critical port infrastructure from terrorism, enhance maritime domain awareness, improve port-wide maritime security risk management, and maintain or reestablish maritime security mitigation protocols that support port recovery and resiliency capabilities. The PSGP is one of the DHS/FEMA grant programs that directly support maritime transportation infrastructure security activities. The PSGP is one tool in the comprehensive set of measures authorized by Congress and implemented by the Administration to strengthen the nation's critical infrastructure against risks associated with potential terrorist attacks. The FY 2019 PSGP provides funds for transportation infrastructure security activities to implement Area Maritime Security Plans and facility security plans among port authorities, facility operators, and state and local government agencies required to provide port security services. The FY 2019 PSGP plays an important role in the implementation of the National Preparedness System by supporting the building, sustainment, and delivery of core capabilities essential to achieving the National Preparedness Goal of a secure and resilient nation. The FY 2019 PSGP's allowable costs support efforts to build and sustain core capabilities across the prevention, protection, mitigation, response, and recovery mission areas. In FY 2019, the total amount of funds under this grant program is $100 million. The FY 2019 PSGP is focused on supporting increased port-wide maritime security risk management; enhancing maritime domain awareness; supporting maritime security training and exercises; and maintaining or reestablishing maritime security mitigation protocols that support port recovery and resiliency capabilities.[93]

[93] Department of Homeland Security.

C. SPENDING

The United States has spent over $2.8 trillion on the global war on terror since the 9/11 attacks, and nearly $1 trillion of that was spent on homeland security initiatives. While war spending fluctuates for a number of reasons, homeland security spending amounts are fairly consistent and show little signs of change. Analysts have begun to question the need, appropriateness, and return on investment of continuing to spend at current levels. As stewards of the public trust, government officials are charged with providing valuable, sought after, and highly competitive resources to the areas that will serve the greatest good to the greatest number. By continuing to focus on threats that were first a focus two decades ago, they risk becoming outdated and overtaken by developing events in an ever-changing world.

There have been relatively few terrorist attacks in the United States since 9/11. The Cato Institute concludes that 172 people were killed in terrorist attacks in the United States from 2002 through 2017. This figure includes people "murdered by terrorists of every ideology including Islamists, white supremacists, environmental extremists, and others regardless of where they were born."[94] Muslim extremists have killed about 100 people in the United States, or about six per year.[95] None of these attacks were related to maritime incidents or involved maritime targets. By comparison, over 69,000 Americans died from drug overdoses in 2018, including more than 32,000 deaths from fentanyl.[96] Mueller and Stewart place the chance of being killed in a terrorist attack in the United States at one in 50 million, comparing that probability to the chance of dying in an automobile accident (one in 8,200), being killed by homicide (one in 22,000), or drowning in the bathtub (one in 950,000).[97] Given that the last recorded domestic maritime terrorist incidents in the United States occurred in the 1970s—with Puerto Rican separatists' relatively benign

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[94] Alex Nowrasteh, "Counterterrorism Spending," *Cato at Liberty* (blog), May 25, 2018, https://www.cato.org/blog/counter-terrorism-spending.

[95] Heeley, *Counterterrorism Spending*, 7.

[96] "National Center for Health Statistics Releases New Monthly Provisional Estimates on Drug Overdose Deaths," Centers for Disease Control and Prevention, September 9, 2019, https://www.cdc.gov/nchs/pressroom/podcasts/20190911/20190911.htm.

[97] Mueller and Stewart, *Public Opinion and Counterterrorism Policy*, 10.

attacks in San Juan and Miami—an argument could be made that there are far more deadly risks in the United States than being killed by a terrorist.

D. MEASURES OF EFFECTIVENESS

Given the paucity of actual attacks—whether successful, thwarted, or uncovered or even planned—it is reasonable to review the need for continued counterterrorism spending at current levels. Questioning whether the $2.8 trillion spent on the global war on terror is an appropriate use of public funds is a legitimate response. Determining whether there is an accurate cost–benefit analysis driving spending decisions when there have been extremely few actual events would shine a light on the process. Another perspective might counter that the resources have been allocated precisely in a manner that has prevented attacks from occurring. A review of the influences on the public from multiple sources is instructive and provides at least a partial understanding of why other threats are not as widely accepted by the public, politicians, and policymakers. It also sets the stage for further discussions of how and why we should routinely reassess our priorities and decision-making processes as threats and vulnerabilities shift.

Friedman's discourse on the influence of cognitive bias and government institutions—agencies and politicians—provides some insight into public perceptions regarding counterterrorism policies and priorities. He states, "Cognitive biases cause people to worry more about terrorists than they should and demand more protection from them," which is necessary from a threat/risk perspective.[98] He notes that the "fear of terrorism is a bigger problem than terrorism."[99] Politicians, government agencies, and the private-sector enterprises providing counterterrorism products all have reason to leverage these fears. By enabling each other, they ensure continued business success, eager customers, and a body politic willing to play to public fears that keeps the cycle going in an endless do-loop. Mueller and Stewart also ascribe blame to government officials who "have maintained their willingness and ability to stoke fear about persistent and evolving

[98] Friedman, "Managing Fear," 77.

[99] Friedman, 78.

threats."[100] All of these influencers can fall prey to the conjunction fallacy, described by Hubbard as follows: "Because we can imagine them more clearly, we often see specific events more likely than broader categories of events."[101] It is relatively easy to imagine terrorists attacking the homeland, bombing infrastructure, and bringing operations to a halt. Hollywood frequently depicts such scenarios—and the heroes that stop them—in movies and television shows. It is far more difficult to imagine slow onset sea level rise attacking infrastructure—a far less likely subject of a feature movie, where the heroes could well be climate scientists or risk managers. This is not exactly a prescription for success in the entertainment world, so little attention is paid to such a script.

These facts also play into the hands of politicians and the military–industrial complex that continues to feed at the trough of government contracts. Perpetuating the fearsome effects of a terror incident feeds into the public's imagination and serves to promote interest in and fear of terrorism, which in turn supports the political argument that counterterrorism should continue to be the focus of the homeland security enterprise. Politicians controlling the purse strings remain in office, and private-sector entities providing counterterrorism goods and services remain engaged, busy, and profitable.

E. PROBABILITIES OF SUCCESS

Maritime terrorism is a low-probability, high-consequence event while sea level rise is a high-probability, high-consequence event. A maritime terrorist incident impacting port infrastructure would likely damage one port as terrorists have not replicated a multiple incident event with any degree of success. Even this would most likely have a limited impact on the nation's economy as ships and their cargoes could be rerouted to undamaged facilities within ports or to other unaffected ports. As Sandler and Enders note, countries like the United States with large and diversified economies typically withstand terrorist events because the incidents are localized, not unlike crimes; the economy can shift emphasis to other sectors; and the economic impacts are generally very short term and

[100] Mueller and Stewart, *Public Opinion and Counterterrorism Policy*, 14.

[101] Douglas Hubbard, *The Failure of Risk Management: Why It's Broken and How to Fix It* (Hoboken, NJ: John Wiley and Sons, 2009), 100.

relatively small.[102] Sea level rise, on the other hand, would know no bounds and affect every port that is unprepared—although to varying degrees depending on regional variances in sea level rise and the vertical land movement impacting vulnerability. Even moderate sea level rise, however, threatens every single port within the coastal zone.

The strategies for homeland security often focus on response. A strong bias toward enhancing first responders' capabilities and preparedness exists throughout the homeland security enterprise. As Lewis notes, however, "critical infrastructure should be protected (through prevention), because prevention is cheaper than suffering mass casualties, economic damage, psychological damage, or damage to national pride."[103]

Immediately following the attacks on 9/11, for example, the USCG closed all U.S. ports for several days to prevent seaborne terrorist attacks to maritime critical infrastructure. The Coast Guard implemented a sea marshal program whereby armed personnel boarded ships entering or departing ports and provided security onboard ships as well as increased the number of vessel escorts and patrols. These measures stayed in place for a short time but then were reduced and modified as the threat envelope changed. Today, USCG assets provide escorts for some vessels, such as liquefied natural gas carriers, cruise ships, and U.S. Navy ships. This is not a full-time activity but more of a case-by-case basis predicated on perceived threats and risk that indicate a need for heightened security.

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[102] Todd Sandler and Walter Enders, *Economic Consequences of Terrorism in Developed and Developing Countries: An Overview* (Washington, DC: World Bank, September 2005), 9–11, http://wenders.people.ua.edu/uploads/2/6/3/8/26382715/econ_consequences_revised.pdf.

[103] Lewis, *Critical Infrastructure Protection in Homeland Security*, 21.

V. SEA LEVEL RISE: AN INESCAPABLE, UNSTOPPABLE RESULT OF A CHANGING CLIMATE

Proving or disproving climate change is beyond the scope of this project. The intent is to report the data that are being measured, make inferences, and provide recommendations based on scientific fact and the projections associated with data collection. Earth's climate is undeniably undergoing large scale changes that are measurable, verifiable, and real. Average temperatures are climbing throughout the world. The year 2019 was the second-warmest year on record, with average temperatures 1.71°F (0.95°C) above the twentieth-century average of 57.0°F (13.9°C).[104] The year 2016 was the warmest on record and nineteen of the twenty warmest years ever recorded all occurred since the year 2001.[105] Extreme weather conditions and associated events occur with far greater frequency than ever experienced. Massive wildfires, drought, devastating hurricanes and cyclones, record high and low and increasing average temperatures; lethal heat waves; extreme precipitation and flooding; and ice sheet melting are all being more routinely reported and associated with a dynamic climate.[106] Agricultural growing seasons are shifting, oceans are warming and affecting migration patterns and the sustainability of fish stocks, sea levels are rising, and natural habitats are changing as forests are being cleared for crops—these are just several of many developments as a growing world population consumes resources and relies on carbon-emitting energy sources.

A. CLIMATE CHANGE

According to the *Fourth NCA* written in 2018, "Earth's climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human

[104] Rebecca Lindsey and LuAnn Dahlman, "Climate Change: Global Temperature," National Oceanic and Atmospheric Administration, January 16, 2020, https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

[105] "Global Temperature," National Aeronautics and Space Administration, accessed January 31, 2020, https://climate.nasa.gov/vital-signs/global-temperature.

[106] Jonathan Woetzel et al., *Climate Risk and Response: Physical Hazards and Socioeconomic Impacts* (San Francisco: McKinsey Global Institute, January 2020), 11–13.

activities."[107] Scientists have conclusively linked global warming to greenhouse gas emissions, primarily related to the burning of fossil fuels and the associated release of carbon dioxide, methane, and nitrous oxide into the atmosphere. The *NCA* notes, "Scientists have understood the fundamental physics of climate change for almost 200 years."[108] The concentration of carbon dioxide in the atmosphere increased by 30 percent since 1950 as fossil fuel dependence has grown, and more forests have been clear-cut for agriculture, industrial needs, and expanding populations and the expanding urbanization of wildlands.[109]

For millennia, worldwide ecosystems have absorbed greenhouse gases to keep pace with natural and manmade emissions and maintain the balance of atmospheric conditions necessary to sustain life on earth. This naturally occurs to keep the planet's oxygen and average temperatures at levels suitable for plants and animals to survive. Plants, and trees in particular, serve as natural carbon dioxide scrubbers, removing harmful gases from the atmosphere and producing oxygen to support life. Some of the gases naturally evaporate or dissipate. The world's oceans also absorb vast amount of gases, up to 90 percent by some estimates.[110] None of these phenomena occurs without consequences, however.

Since the advent of the Industrial Age in the late 1800s, the rate of carbon dioxide released into the atmosphere has climbed dramatically, primarily due to burning fossil fuels, deforestation, and changes in land use. One estimate indicates that releases of carbon dioxide into the atmosphere are occurring 10 times faster than at any time in the last 66 million years.[111] This has led to unprecedented increases in average temperatures and other climatic changes.[112]

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[107] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 34.

[108] U.S. Global Change Research Program, 39.

[109] Loiy Al-Ghussain, "Global Warming: Review on Driving Forces and Mitigation," *Environmental Progress & Sustainable Energy* 38, no. 1 (January/February 2019): 14, https://doi.org/10.1002/ep.13041.

[110] Christina Nunez, "Sea Level Rise, Explained," *National Geographic*, February 19, 2019, https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/.

[111] Damian Carrington, "Carbon Emission Release Rate 'Unprecedented' in Past 66M Years," *The Guardian*, March 21, 2016, https://www.theguardian.com/environment/2016/mar/21/carbon-emission-release-rate-unprecedented-in-past-66m-years.

[112] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 39.

Some of the most dramatic, long-lasting, and significant impacts of increased greenhouse gas emissions have been on Earth's oceans, which naturally absorb carbon dioxide and other gases. Approximately 71 percent of Earth's surface is covered by ocean that contains approximately 97 percent of Earth's water. In addition, about 10 percent of Earth's land area is covered by glaciers or ice sheets, collectively known as the cryosphere.[113] The 2019 IPCC report on climate change provides startling facts regarding the impacts of a changing climate and increasing temperatures on Earth's oceans and cryosphere:

> Over the last decades, global warming has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers, reductions in snow cover and Arctic sea ice extent and thickness, and increased permafrost temperature. It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system. Since 1993, the rate of ocean warming has more than doubled. Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity. By absorbing more CO2, the ocean has undergone increasing surface acidification.[114]

Many of the ecosystem impacts related to climate change are linked because they perpetuate each other in a continuous cycle. For example, one impact of warming temperatures is the melting of Arctic sea ice. As temperatures rise, more ice melts. This melting ice increases the water surface, which is darker than ice and, thus, leads to more sunlight and heat absorption vis-à-vis white, reflective, snow-covered ice, which results in even more heating of the water, leading to more ice melting. In another example, the relative salinity of water from ice melting also affects ocean circulation speed, range, and salinity, which have long-lasting impacts. Under some scenarios, the Atlantic Ocean Meridional Overturning Current, also known as the Gulf Stream, shows a weakening and probability of shutdown.[115]

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[113] Pörtner et al., *Special Report on the Ocean and Cryosphere*, 5.

[114] Pörtner et al., 6, 9.

[115] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 98–99.

B. IMPACTS OF A CHANGING CLIMATE

There is some debate among politicians, industrialists, media, and some scientists regarding the pace, scale, and causes of global climate change. Whether these arguments are self-serving or serve specific constituents or other stakeholders is open for debate. The basis for this treatise has been constructed with the assumption that a changing climate is a reality and, although projections vary, multiple scenarios are probable, and worst-case scenarios are quite possible. This will be examined in some detail to provide a baseline for more specific assumptions and the discussion that follows.

The impacts of climate change are not something that can be quickly stopped or reversed. Emissions that have been and continue to be released into the atmosphere will continue to influence climate for decades if not centuries to come. We have reached a point where emissions exceed Earth's natural capability and capacity to remove them by natural activities. This will continue to increase global air and water temperatures.[116] Contrary to arguments that science does not have the tools or models for accurate predictions, recent studies indicate that projections made since the 1970s have been extremely accurate, as the fidelity and precision of predictions are getting better and more accurate.[117] As the authors of a study examining the accuracy of studies from the last 50 years put it, "We find that climate models published over the past five decades were skillful in predicting subsequent global mean surface temperature changes, with most models examined showing warming consistent with observations."[118] This skillfulness is due in part to better observations, increased computer modeling capabilities, and a deeper understanding of the complexities of emissions and absorption by ecosystems. These aspects provide scientists with a stronger understanding of the many variables associated with climate change as well as greater confidence in their findings and predictions.[119]

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[116] U.S. Global Change Research Program, 40.

[117] Roberts, "Scientists Have Gotten Predictions of Global Warming Right."

[118] Zeke Hausfather et al., "Evaluating the Performance of Past Climate Model Projections," *Geophysical Research Letters* 47, no. 1 (2020): 1, https://doi. org/10.1029/2019GL085378.

[119] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 40.

Even with stronger confidence in predictions, there is still a great deal of uncertainty regarding the scale of climate change impacts. The complexity and sheer amount of unknown and unquantifiable variables make it impossible to accurately predict the precise changes that can be expected. Researchers provide a range of expectations based on models, simulations, and data. There are no A and B samples that can be compared as a classic control device to run experiments—there is only one Earth to monitor and measure. While providing a range of calculations presents an opportunity for variance and affords policymakers room to maneuver in their decisions, it also provides best- and worst-case scenarios that can be used to bracket recommendations to assist planners.

The IPCC report is the foundation for many other organizations, governments, agencies, and businesses in their deliberations and policy planning. The report provides a range of climate change–related predictions, from virtually certain, likely, unlikely, to exceptionally unlikely. The predictions were determined through a process that included evaluations with three distinct lenses: evidence and agreement, confidence, and statistical likelihood.[120]

The IPCC first developed ranges, called representative concentration pathways (RCPs), in 2005. The IPCC's fifth assessment in 2014 refines the breadth of RCPs for current and future reference in depicting climate change scenarios.[121] The RCPs are greenhouse gas emission levels that are used as a baseline for predictions of the severity and range of environmental changes based on the amount and rate of emissions. The IPCC describes RCPs as "scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover."[122] The RCPs standardize approaches across multiple disciplines and provide a consistent methodology for comparison that ensures similarity, reliability, and repeatability across domains. They also afford planners and decision makers a means to incorporate scenarios into their planning efforts.

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[120] Pörtner et al., *Special Report on the Ocean and Cryosphere*, 42.

[121] Rajendra K. Pachauri and Leo A. Meyer, *Climate Change 2014: Synthesis Report* (Geneva: Intergovernmental Panel on Climate Change, 2015).

[122] Pörtner et al., *Special Report on the Ocean and Cryosphere*, 8.

The range of RPCs span the lower end (RCP 2.6) to the upper end (RCP 8.5) of carbon dioxide emissions.[123] These pathways, in turn, drive the potential scenarios for the various sectors that could be affected by a changing climate. RCP 2.6 establishes that the increase in average global temperature by the year 2100 will likely be between 0.9 and 2.4ºC. The likely range of temperature change under RCP 8.5 is 3.2 to 5.4ºC.[124] As noted, increasing temperatures are directly related to warming oceans, melting ice sheets, and subsequent sea level rise. The project is very specific in reporting with strong confidence that global mean sea level rise is occurring at unprecedented rates. The IPCC report notes that not only are sea levels rising, but the rate of rise is accelerating.

Several factors contribute to this phenomenon. Sea level rise is not uniform throughout the world as regional variations in salinity, ocean currents, and geographic anomalies influence the oceans. As ice loss in the Antarctic and Greenland ice sheets accelerates, colder freshwater enters the northern oceans, and this also affects ocean dynamics, particularly in the Atlantic Ocean. Glacial ice losses due to rising temperatures also contribute to sea level rise through thermal expansion as the oceans warm.[125] In addition, the *Fourth NCA* notes that when sea temperatures increase, seawater expands and increases the overall volume of water in the oceans in an effect called thermal expansion. Furthermore, as more of the ice sheets melt, the volume of water in the oceans increases, exacerbating thermal expansion and raising sea levels worldwide.[126]

RCPs are widely accepted throughout the scientific community for projections and planning. The *NCA* refers to both the low and high RCPs in examining potential effects of sea level rise, noting that because these events are possible, future risk management should include these possibilities in assessments.[127] A recent study by the McKinsey Global Institute, "Climate Risk and Response," published in January 2020 states that RCP 8.5 was used as the basis for its report "because the higher-emission scenario it portrays enables us

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[123] Woetzel et al., "Climate Risk and Response," viii.

[124] Pörtner et al., *Special Report on the Ocean and Cryosphere*, 8.

[125] Pörtner et al.

[126] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 84.

[127] U.S. Global Change Research Program, 329.

to assess physical risk in the absence of further decarbonization . . . that illustrate[s] exposure to climate change extremes and proximity to physical thresholds."[128] Most importantly, since the inception of RCPs in 2005, RCP 8.5 has consistently shown the most accurate projections of actual greenhouse gas emissions, particularly carbon dioxide concentrations.[129]

For the purposes of this exercise, to ensure consistency and provide a comparable assessment, the higher scenario (RCP 8.5) was used to form the basis of study and comparison. This was decided after a detailed review of scientific literature, government policies, and national, regional, and localized planning documents. Therein is the conundrum all risk managers face: how and where to allocate precious resources based on threat analyses determined from the best information available. A worst-case scenario might appear at first glance to be too heavy-handed, but this is also the reality that homeland security planners use to develop threat and risk matrices to identify vulnerabilities that guide their resource allocation.

In addition, rather than looking at the near future of 20 to 30 years as the McKinsey study does, this project focused on projections for the year 2100. By intentionally looking forward 80 years, we could match climate-related phenomena with infrastructure life-cycle costs and expected lifespans to portray impacts on specific regions. This assessment was based on hypothetical scenarios, but as projections should continue to be refined and improved, greater clarity may be applied to those projections. Hausfather et al. provide increased confidence in recent projections: "This research should help resolve public confusion around the performance of past climate modeling efforts and increases our confidence that models are accurately projecting global warming."[130]

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[128] Woetzel et al., "Climate Risk and Response," viii.

[129] Woetzel et al., 42.

[130] Hausfather et al., "Evaluating the Performance of Past Climate Model Projections," 1.

C. SEA LEVEL RISE

Sea level rise is present and accelerating. According to the *NCA*, global mean sea levels rose four to five inches from 1901 to 1990, and about three inches from 1990 to 2015.[131] One body of research indicates that there is a 95 percent probability that the change from 1900 to 2000 was greater than any other previous century in the last 3,000 years.[132] This acceleration is expected to continue well into the 21st and 22nd centuries if greenhouse gas emissions do not level off or decline significantly. The combination of greenhouse gases already emitted and those that will be emitted in the coming decades are key contributors to continued warming and subsequent rising sea levels. The *NCA* notes that "even under a very low scenario (RCP 2.6), projections indicate that the frequency, depth, and extent of both high tides and more severe, damaging coastal flooding will increase rapidly in the coming decades. Under the higher scenario (RCP 8.5), an extreme global sea level rising upwards of 8 feet by 2100 is a possibility."[133]

When examining global sea level rise projections, several factors should be considered. First, the projections are a global mean. This indicates the best assessment of how much the global mean sea level will rise by the year 2100 given that emissions continue at the rate projected in this scenario. Second, sea level rise will vary greatly by region due to ocean current routes, vertical land movement due to subsidence caused by draining aquifers and geological shifts, and the impact of melting Arctic ice.[134] The IPCC states, "Regional differences, within ±30 percent of the global mean sea level rise, result from land ice loss and variations in ocean warming and circulation. Differences from the global mean can be greater in areas of rapid vertical land movement including from local human activities (e.g. extraction of groundwater)."[135] These are important influencers when examining specific local predictions for future sea level rise. Third, even if

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[131] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 107.

[132] C. C. Hay et al., "Probabilistic Reanalysis of Twentieth-Century Sea-Level Rise," *Nature* 517 (2015): 481–84, https://doi.org/doi:10.1038/nature14093.

[133] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 329.

[134] U.S. Global Change Research Program, 75.

[135] Pörtner et al., *Special Report on the Ocean and Cryosphere*, 10.

greenhouse gas emissions are sharply reduced, the oceans, land, and other carbon stores will continue to release carbon dioxide and other gases into the atmosphere for decades to come. This will continue to have a significant impact on climate change–related phenomena worldwide.

Under RCP 8.5, a number of global and localized projections have been made. In this scenario, based on current observations and modeling, global sea level rise is predicted with confidence to increase up to four feet by 2100. It is important to reiterate that this is the global mean and that localized changes can and will differ. Additional models that account for increased Antarctic ice sheet melt contributions to sea level rise indicate that a rise of eight feet or more is possible.[136] The report assigns differing levels of confidence to the predictions, with those that are further into the future assigned less confidence due to greater variability over time. The report does state that data from the most recent studies (2016 and 2017) provide a very likely range for sea level rise of 1.9–8.0 feet.[137] It is important to note again that these are projections for global mean sea level rise and that local variances could be significant. Factoring in the IPCC projection of ±30 percent for regional variance, the potential upper ranges for sea level rise increase to 2.47–10.4 feet.

D. SPECIFIC U.S. PROJECTIONS

Narrowing the focus to the United States, regional differences in land substructure, vertical land movement, ocean circulation, severe weather patterns, and tidal ranges all factor into sea level rise. Porous and swampy land common on stretches of the East and Gulf Coasts is more susceptible to inundation than the rocky substructure common on the Pacific and New England Coasts. The *NCA* notes, for example, that "relative sea level rise is projected to be greater than the global average along the coastlines of the U.S. Northeast and the western Gulf of Mexico due to the effects of ocean circulation changes and sinking land."[138] Hurricanes and tropical storms push walls of water ahead of them as storm surges, which will be exacerbated with higher sea level averages. Ocean currents, particularly in

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[136] U.S. Global Change Research Program, *Fourth National Climate Assessment*, 106.

[137] U.S. Global Change Research Program, 108.

[138] U.S. Global Change Research Program, 99.

the Atlantic Ocean, also affect average sea levels and tidal ranges. The Gulf Stream along the U.S. Eastern Seaboard is not level, for example. It varies from three to five feet in height across its width, with the higher areas generally on the eastern side. With projections that show a weakening and potential stopping of the flow, this variance will change, and the water must go somewhere.[139] Regions with high tidal ranges and low-lying shorelines will be affected more than areas with higher relative shorelines and lower tidal ranges. For example, the San Francisco Bay area experienced a king tide of greater than seven feet in January 2020. If projections for 2100 become a reality, this same phenomenon would result in sea water inundation of nine to 15 feet above current levels.

The Port of Virginia and the Hampton Roads region are especially susceptible to many of these effects that will exacerbate rising sea levels. The region is experiencing vertical land movement rates due to subsidence caused by Earth's crust lowering from compaction, structures built on fill that also compacts over time, and aquifers drained for groundwater.[140] Atkinson et al. project that this area could see the highest sea level rise rate in the United States. The Port of San Diego does not face threats of the same magnitude, but rising sea levels will affect every region to some degree. Given the strategic importance and intrinsic value of maritime infrastructure to national security and economic viability in these and many other ports, the threats posed to these assets need to be addressed before it is too late.

For the purposes of addressing the vulnerabilities associated with the nation's maritime infrastructure and the Ports of Virginia and San Diego, this study focused on a global mean sea level rise of two meters. This level was selected for several reasons. It falls within the range of predicted levels under RCP 8.5 of two to eight feet, as previously discussed. This level also has a distinct possibility of becoming a reality. Figures 4 through 7 provide a comparison of the two regions, depicting current sea levels and projections for a five-foot sea level rise at each port. The NOAA's sea level rise viewer shows the effects of the proposed sea level rise on the Ports of Virginia and San Diego. These images indicate

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[139] Larry P. Atkinson, Tal Ezer, and Elizabeth Smith, "Sea Level Rise and Flooding Risk in Virginia," *Sea Grant Law and Policy Journal* 5, no. 2 (Winter 2013): 3–14.

[140] Atkinson, Ezer, and Smith, 6.

that the Norfolk area would suffer much greater losses than would San Diego, due to the nature of land elevation.

Although the Paris Climate Accord of 2016 calls for industrial nations to reduce greenhouse gas emissions, the Accord is voluntary, not compulsory, and the United States, one of the world's largest producers of greenhouse gases, is withdrawing from the agreement in 2020. Without U.S. leadership and participation, it is likely that other countries will follow suit and not comply with the agreement. It is highly likely that the goal of capping temperatures at 2°C above pre-industrial levels in this century and enacting measures to limit future increases to 1.5°C will not be reached.[141] If this is the case, the aforementioned scenarios—and particularly RCP 8.5—will become a reality. Greenhouse gas emissions continue unabated; global temperatures steadily rise; Arctic, Greenland, and Antarctic ice sheets are melting at an accelerating pace; oceans are warming and expanding; and relentless sea level rise persists.

[141] "The Paris Agreement," United Nations, accessed March 3, 2020, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

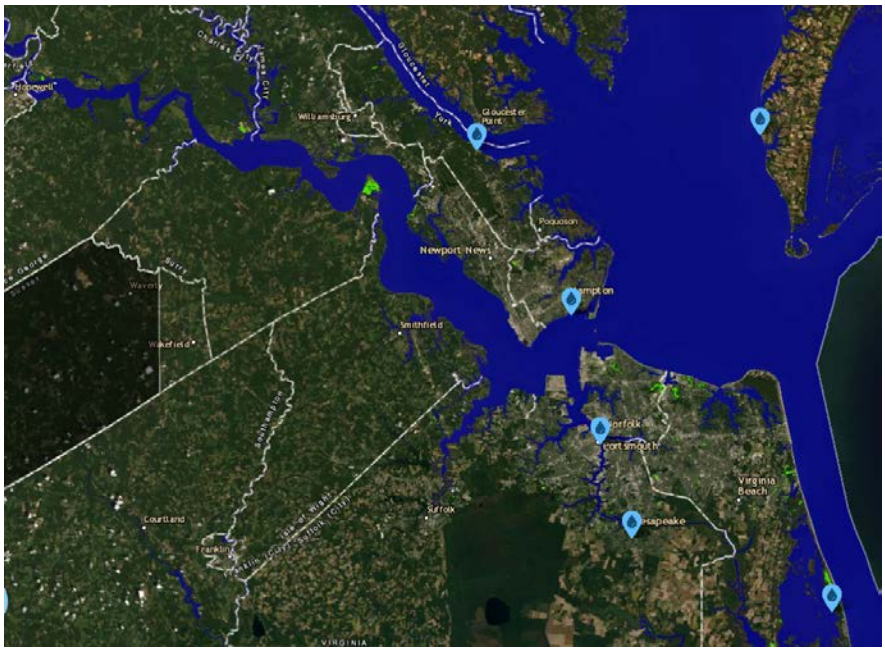

Figure 4. Depiction of Current Sea Levels, Hampton Roads Region[142]

Figure 5. Inundation Predictions with a Five-Foot Sea Level Rise, Hampton Roads Region[143]

[142] Source: National Oceanic and Atmospheric Administration, "Sea Level Rise Viewer."

[143] Source: National Oceanic and Atmospheric Administration.

Figure 6. Current Sea Level in the San Diego Harbor[144]

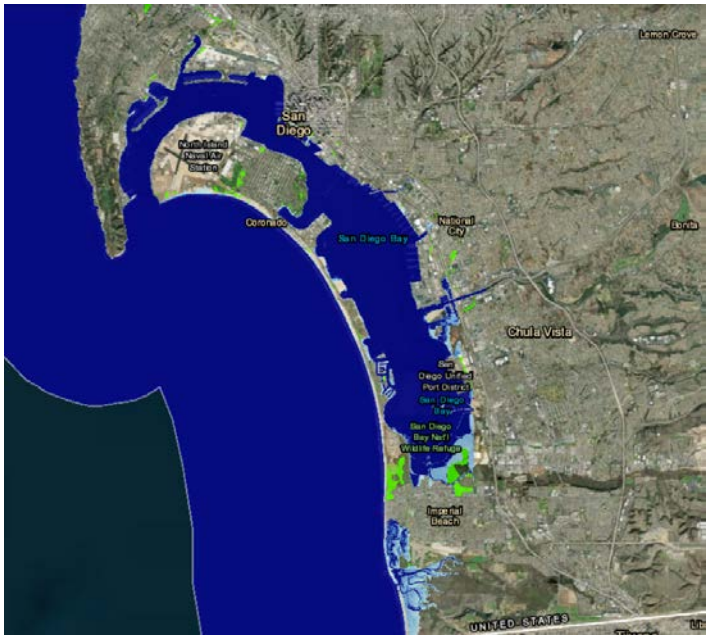

Figure 7. Inundation Predictions with a Five-Foot Sea Level Rise in the San Diego Harbor[145]

[144] Source: National Oceanic and Atmospheric Administration.

[145] Source: National Oceanic and Atmospheric Administration.

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VI. INFRASTRUCTURE IMPLICATIONS AND IMPACTS

The IPCC's report provides a worldview of climate change–inducing sea level rise, predicting changes in terms of global mean sea level rise without focusing on specific locales. Several studies provide predictions for regional and local effects that provide insight and baselines for determining the reach of inundation and the specific areas that will be affected. For the Port of Virginia, both the 2017 Hampton Roads Intergovernmental Pilot Project and a report by Van Houtven et al. provide comprehensive projections and impact assessments for the Port of Virginia.[146] The Port of San Diego's 2019 *Sea Level Rise Vulnerability Assessment* and coastal resiliency report provide studies on various scenarios and contain methodologies and predictions for future impacts.[147] These and other studies as noted are employed here to assess sea level rise threats to maritime infrastructure and are compared with metrics proposed by additional independent studies to evaluate efficacy and consistency.

A. IMPLICATIONS FOR THE PORT OF VIRGINIA

The Port of Virginia and the Hampton Roads area have been identified as one of the most vulnerable regions to sea level rise in the country, second only to New Orleans in terms of risk and one of the top 10 most valuable economic regions at risk to exposure from climate change in the world.[148] This is due to a number of contributing factors, as previously noted, including vertical land movement, changing oceanic currents, and thermal expansion. Eggleston and Pope note that in the Port of Virginia region, land has been sinking for millions of years, primarily due to long-term geologic processes, and in

[146] Center for Sea Level Rise, "Center for Sea Level Rise"; Van Houtven et al., "Costs of Doing Nothing."

[147] Port of San Diego, *Sea Level Rise Vulnerability Assessment*.

[148] Center for Sea Level Rise, "Center for Sea Level Rise"; R. J. Nicholls et al., "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes, Exposure Estimates" (Paris: Organisation for Economic Development and Cooperation, November 19, 2008), 3.

some places, the land is sinking even faster due to groundwater extraction.[149] These factors have exacerbated local sea level rise, as the Chesapeake Bay has risen at more than double the rate of the estimated global sea level rise from 1927 to 2006, one of the highest rates of sea level rise on the Atlantic coast.[150] The Virginia Institute of Marine Science estimates that local sea level rise within the Port of Virginia footprint will be one to two meters by the year 2100 due to the combination of global sea level rise and land subsidence.[151]

The Center for Sea Level Rise identifies maritime infrastructure vulnerable to sea level rise at the Port of Virginia (Figure 8). Nearly 900 miles of roads could be routinely or even permanently flooded with a sea level rise of just one to three feet, well within RCP 8.5 projections. About 45,000 acres of land are expected to be lost in Virginia Beach with a four-foot sea level rise. The Center also notes that the Norfolk Navy Base is replacing 14 World War II piers due to impacts from rising sea levels at a cost of $35–$40 million per pier. The projected cost of losses in the region caused by a three-foot sea level rise extends in upward of $87 billion.[152] The primary impact driving the costs are damages to infrastructure and buildings that interrupt trade, transportation, and commerce.[153]

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[149] Jack Eggleston and Jason Pope, *Land Subsidence and Relative Sea-Level Rise in the Southern Chesapeake Bay Region*, U.S. Geological Survey Circular 1392 (Reston, VA: U.S. Geological Survey, 2013), 15, https://pubs.usgs.gov/circ/1392/pdf/circ1392.pdf.

[150] Eggleston and Pope, 18.

[151] Van Houtven et al., "Costs of Doing Nothing," ES-1.

[152] Center for Sea Level Rise, "Center for Sea Level Rise."

[153] Van Houtven et al., "Costs of Doing Nothing," 2–5.

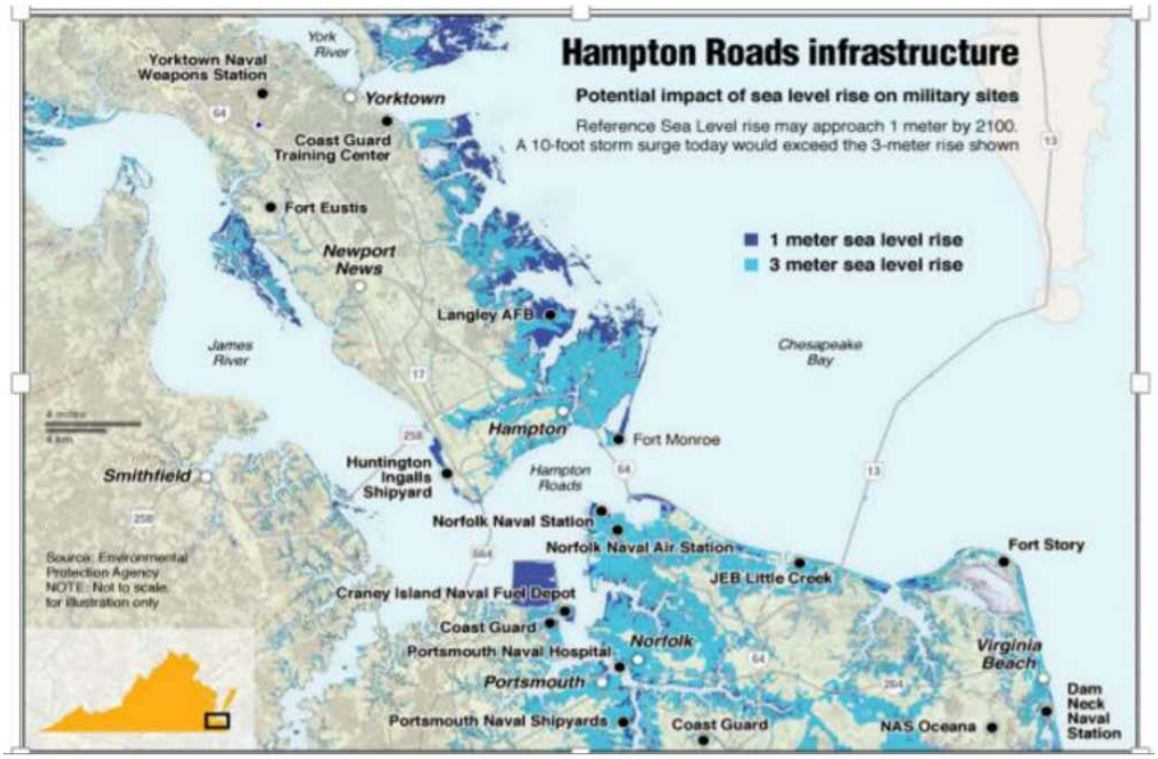

Figure 8. Military Facilities at Risk to One-Meter and Three-Meter Sea Level Rise in the Hampton Roads Region[154]

B. IMPLICATIONS FOR THE PORT OF SAN DIEGO

The Port of San Diego completed an assessment of sea level rise vulnerability in 2019. The assessment settled on RCP 8.5 as the standard for projecting near and long-term climate change impacts on the region. This would lead to a 4.5-foot sea level rise at the Port of San Diego. Although this level has a one in 20 chance of occurring, it was selected to demonstrate the worst-case scenario so that planners and risk managers could comprehend the potential damages associated with sea level rise. The authors note that this also accounts for continued greenhouse gas emissions and the unknown impacts of melting ice sheets.[155]

[154] Source: Matt Connolly, "Hampton Roads, Virginia and the Military's Battle Against Sea Level Rise," Briefer No. 27 (Washington, DC: Center for Climate and Security, October 14, 2015): 3.

[155] Port of San Diego, *Sea Level Rise Vulnerability Assessment*, 4–5.

A detailed assessment of infrastructure projected to be impacted includes roads; rail; the airport; marine terminals; wharves, piers, and the associated equipment in and on them; and stormwater systems. These assets are labeled "critical infrastructure" in the report.[156] Similar to the Port of Virginia, the Port of San Diego notes that the loss of transportation and other related infrastructure would lead to the greatest financial losses. The specific maritime infrastructure assets exposed to inundation from this sea level rise scenario include 26 percent of roads, 57 percent of rail, 37 percent of marine terminals on 86 acres, 23 percent of the buildings, and 75 percent of all piers.[157] Total estimated losses are projected to be $922.1 million with nearly $40 million in annual revenue losses by the year 2100.[158]

[156] Port of San Diego, 33.

[157] Port of San Diego, 8.

[158] Port of San Diego, 14.

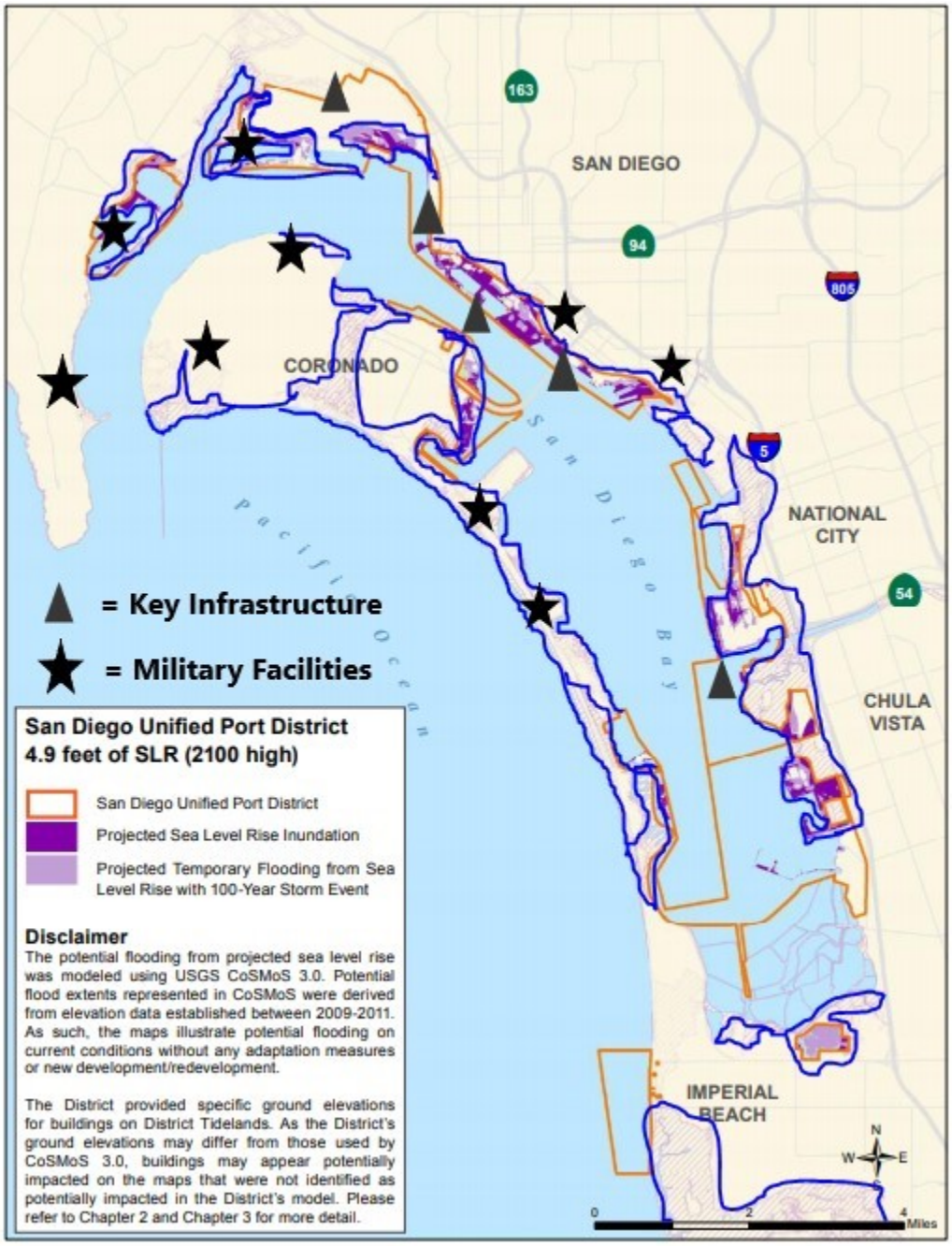

Figure 9. Sea Level Rise in the San Diego Harbor of 4.9 Feet (1.5 Meters) with Projected Inundation and Infrastructure at Risk[159]

NOAA's assessments provide more details on regional sea level rise projections. In a 2017 report, NOAA sets out to bound upper-level rises for the year 2100 based on peer-

[159] Adapted from Port of San Diego, 47.

reviewed literature, observations, and modeling that includes melting Antarctic and Greenland ice sheets. The report finds there is "evidence to support a physically plausible global mean sea level rise in the range of 2.0 to 2.7 meters, and recent results regarding Antarctic ice sheet instability indicate that such outcomes may be more likely than previously thought. . . . We recommend a revised 'extreme' upper-bound scenario for global mean sea level of 2.5 meters by the year 2100."[160] The report also singles out regional sea level rise variations from the global mean projections:

> Along regions of the Northeast Atlantic (Virginia coast and northward) and the western Gulf of Mexico coasts, the sea level rise is projected to be greater than the global average for almost all future global mean sea level rise scenarios. Along almost all U.S. coasts outside Alaska, the sea level rise is projected to be higher than the global average under the Intermediate-High, High and Extreme scenarios.[161]

These findings provide more reference points for planners to approach their work but also demand that this be a dynamic rather than static approach—as more data are collected and science obtains a better understanding of all the components influencing climate change—as they develop adaptation and mitigation plans.

C. ADAPTATION AND MITIGATION

Adaptation to sea level rise includes four basic approaches. The first is to do nothing and hope that technology provides solutions to rising temperatures; melting ice sheets; warming, slowing, and acidifying oceans; and the accompanying sea level rise. A second adaptation methodology is to protect infrastructure through building defensive measures to prevent inundation. A third measure is to accommodate these changes by altering at risk infrastructure to reduce impacts. This can include raising infrastructure levels or moving vital equipment out of harm's way. Another form of adaptation is called advancement. This approach calls for developing coastal barriers such as wetlands, reefs, and beaches that act

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[160] William V. Sweet et al., *Global and Regional Sea Level Rise Scenarios for the United States* (Silver Spring, MD: National Oceanic and Atmospheric Administration, January 2017), vi.

[161] Sweet et al., vii.

as buffers for rising seas. Retreat is the final option for adaptation. This concept involves moving infrastructure out of the impact zones to safe locations.

All of these adaptation approaches carry inherent risks and variable costs. Some are not feasible for specific locations, some are costlier than others, and some are simply impossible to implement. All require in-depth analysis and long-term planning to ensure effectiveness and economic viability, that is, to ensure the cost of the action does not outweigh the savings gained from the strategy. The IPCC notes that the slower that changes to the climate occur, the more successful the chances of adaptation practices will be. However, this will potentially require billions of dollars of investments.[162]

In some locations, mitigation plans may include dikes, seawalls, and barriers. These are physical devices that would be built to prevent inundation. They might not be feasible, however, in terms of both practicality and cost effectiveness. For example, building seawalls and barriers might prove technologically impossible given the 18-mile-wide opening of the Chesapeake Bay to the Atlantic Ocean. When combined with naturally occurring land subsidence rates and higher sea level rise in the region, this may not even be a practical option, much less an affordable solution.

D. MODELING SOLUTIONS

Several modeling tools were used to validate the cost impact of sea level rise in the two ports involved in this study. Developing exceedance probability curves is one method of evaluating risk and corresponding economic losses. Such a curve would describe the probability of economic loss that exceeds established levels. This can be applied to sea level rise scenarios to model effectiveness of adaptation compared to the risk of loss.[163] Jiang et al. looked at storm surge in Ise Bay, Japan, related to climate change. The complexity of their modeling is beyond the scope of this exercise, but their work could be adapted to sea level rise in any maritime port.

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[162] Pörtner et al., *Special Report on the Ocean and Cryosphere*.

[163] Xinyu Jiang et al., "Simulation-Based Exceedance Probability Curves to Assess the Economic Impact of Storm Surge Inundations Due to Climate Change: A Case Study in Ise Bay, Japan," *Sustainability* 11, no. 4 (January 2019): 2, https://doi.org/10.3390/su11041090.

Another perspective is to review specific adaptation efforts to mitigate sea level rise, such as building levees. Peng and Song propose conducting cost–benefit analyses to "assess the cost efficiency . . . by estimating the avoided damages of implementing levee projects."[164] They suggest that conducting effective cost–benefit analyses before implementing adaptation plans is critical to successfully planning and funding projects such as this because of the long lead and life times, not to mention the need to account for appreciation and time value of money. While the paper's focus is primarily storm surge, the authors do tie in sea level rise, noting the importance of coastal infrastructure planners' awareness of the cost and benefits before developing adaptation strategies: "Making large investments and associated maintenance costs (have become) a significant issue in the coastal protection process."[165]

The GenPort modeling tool is perhaps the least complex tool to assess potential replacement and adaptation costs. Applying the GenPort model developed by Becker et al. finds that the cost of raising a port one meter is approximately $31 million per square kilometer and an additional $92 million to $142 million per square kilometer to reconstruct infrastructure. In their analysis, total costs for raising a maritime port by two meters and reconstructing infrastructure would approach $200 million per square kilometer.[166] The calculations provide a methodology for comparison with loss projections for the Ports of Virginia and San Diego.

The following examples provide a glimpse of overlaying an assessment tool on studies to approximately validate data and findings. The Port of Virginia's assessments conclude that a sea level rise of just three feet would result in economic losses of $87 billion.[167] The City of Norfolk alone would lose 45,000 acres or 182 square kilometers of land to sea level rise. An acre is equal to 0.00404686 square kilometers. Using the GenPort

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[164] Binbin Peng and Jie Song, "A Case Study of Preliminary Cost-Benefit Analysis of Building Levees to Mitigate the Joint Effects of Sea Level Rise and Storm Surge," *Water* 10, no. 2 (2018): 1, https://doi.org/10.3390/w10020169.

[165] Peng and Song, 2.

[166] Becker, Hippe, and Mclean, "Cost and Materials Required to Retrofit US Seaports," 12–13.

[167] Center for Sea Level Rise, "Center for Sea Level Rise."

formula, the resultant loss would be 182 square kilometers x $200 million per square kilometer. The total would be $36.4 billion in losses. Assuming this land is all associated with port infrastructure, then we begin to approach the numbers found in the study. Of note, these projections are for a three-foot rise in sea level, and as we have established, the Port of Norfolk will likely see a much higher rise and, therefore, greater inundation and more widespread damage. The actual Port of Virginia is spread over 1,573 acres.[168] Assuming that two-thirds of the port will be affected by sea level rise, 1,054 acres are at risk.

As previously noted, the Port of San Diego reports that under RCP 8.5, sea level rise will cause estimated losses of $922.1 million.[169] The port has 233.4 acres of marine terminals within its footprint. The report estimates that a sea level rise of 4.5 feet will inundate approximately 37 percent or 86 acres by the year 2100. Eighty-six acres are equivalent to 0.35 square kilometers. Using the GenPort model, 0.35 square kilometers x $200 million per square kilometer equals $70 million (Table 1).

Table 1. Summary of Estimated Costs to Mitigate Sea Level Rise at the Ports of Virginia and San Diego

Location	Port of Virginia	Port of San Diego
Total Acres	1,573	233.4
Acres at Risk RCP 8.5	1,054	86
Square km	4.27	0.35
Cost to Raise Six Feet	$854 million	$70 million

Several caveats accompany these calculations. As noted by Becker et al., this cost estimation provides a very rough approximation of losses and is generally limited to surface components that will be inundated. Moreover, the model is not all inclusive. It does not include roads, rail, and airports or the connections linking them to ports. It does not account

[168] John F. Reinhart, "Charting a Course for Success" (presentation, Port of Virginia, November 12, 2014), http://www.virginiadot.org/2014_Governor_Conference/documents/Charting_a_Course_for_Success_VAPort_John_Reinhart.pdf.

[169] Port of San Diego, *Sea Level Rise Vulnerability Assessment*, 8.

for lost revenue and residual impacts to the economy. The Port of San Diego, for example, reports anticipated losses of nearly 22 miles of roads and rail, 11 piers, 206 stormwater management elements, and 136 buildings with a sea level rise of 4.5 feet. Military facilities and commercial airports in the region are not included in these projections, which would increase costs significantly.

Despite shortcomings, the GenPort model is a tool that can be used by planners to provide a rough estimate of potential physical losses due to sea level rise. As a rudimentary comparison of the two ports, it makes sense that losses in the Port of Virginia are significantly greater that San Diego given the exposure, projections, risk, and vulnerability differences between the two locations. A more rigorous analysis with more sophisticated modeling tools is vital for comprehensive estimates of losses at each maritime port.

VII. SEA LEVEL RISE IS NATURE'S WEAPON OF MASS DESTRUCTION

This project was conceived as an effort to determine the financial value of the resources allocated by the federal government to countering maritime terrorism in the United States and compare that value with the potential loss of maritime infrastructure in maritime ports. From there, a cogent argument was made to prioritize highly sought-after resources based on cost–benefit analyses, examining threat vectors, risk matrices, and vulnerability analyses. Like all good strategies, approaches tend to shift when contact is made with the subject of the plan. This exercise was no different, resulting in course changes in unpredicted directions but still leading to conclusive if unanticipated results.

A. RESPONDING TO THE GREATEST THREATS WITH THE BEST APPROACHES

Defining infrastructure provided valuable insight into the many integers that compose the MTS. While ports are unique in scale, functionality, and vulnerability to sea level rise and weather patterns, they do share many commonalities that facilitate comparative analysis. Creating a baseline and common operating picture of what was included in the definition, and, just as importantly, what was not included provided the foundation for establishing reference points to conduct the analysis. In addition, this afforded a more balanced approach when scaling up to national-level policies and directives. For example, the piers, wharves, and docks are often the first components that come to mind when describing maritime port infrastructure, particularly in terms of risk to sea level rise. However, their accoutrements such as cranes, power, water sources, and data lines are just as vital to supporting the flow of commerce and cannot be overlooked.

Roads, rail lines, and airports are also key components and are often out of necessity located on, near, or over the water. Terminals and aprons support storing and moving goods. Warehouses and other buildings are on the waterfront to support operations. Importantly, access to the facilities linking ships to shoreside transportation routes is critical to successfully and efficiently moving goods and services. The roadways and rail spurs connecting main lines are vital and often at great risk. The many additional elements

directly linked to this particular dataset, and serving as supporting elements to these critical nodes, were identified and incorporated into the equation.

Determining value for this vast array was quite challenging. Several sources were leveraged to assess the values assigned to different types of infrastructure including replacement values, initial cost estimates, and estimates linked to adaptation and mitigation strategies. Each has individual characteristics that help define it and bound the problem set. The Ports of Virginia and San Diego both conducted research on potential losses. The research found that both ports used similar methodologies in their calculations of value and generally aligned with parameters described in other valuation tools, including those cited by Becker et al. and Houtven et al.[170] Therefore, the valuations provided in the two reports were deemed appropriate for use in the comparative analysis of the regional reports.

In addition to the costs to physically rebuild, replace, or reinforce existing infrastructure, there is significant intrinsic value in the opportunity costs associated with losing nodes or hubs and the connections to the outlying spokes. Determining precise contributions by maritime operations to the economy and to national security writ large is virtually impossible given the multiple variables, approaches, and options available for consideration. For example, calculating the opportunity cost of losing three piers, two roadways, and one rail line at the Port of Virginia requires complex computing that exceeds the capabilities available at this juncture. Calculating the actual physical losses in terms of replacement costs was achievable but should come with the caveat that total economic loses are rough estimates based on overall port contributions to local and regional gross domestic products. Segregating specific component contributions within each port was not possible in this effort.

Despite best efforts, it was impossible to determine precisely what homeland security spending levels are at the federal level. As noted, rough estimates can be gleaned from contributing departmental and agency budget allocations, grants, and ancillary avenues such as independent studies. Several papers reported similar findings, such as the

[170] Becker, Hippe, and Mclean, "Cost and Materials Required to Retrofit US Seaports," 21; Van Houtven et al., "Costs of Doing Nothing."

Stimson study, the Cato Institute, and Mueller and Stewart, all of which contributed to the body of work with deliberate attempts to determine spending levels, assess spending rationale, and provide theories behind spending decisions.[171] These are important factors in considering why and where resources are allocated.

The Stimson report put homeland security spending between 2002 and 2017 at $978.5 billion.[172] In another study, Mueller and Stewart calculated that overall terrorism spending by the United States was about $100 billion annually.[173] Assuming little or no reduction in spending levels during the intervening years, it is safe to assume that the total for homeland security spending since 2002 is well in excess of $1 trillion. The Department of Homeland Security's fiscal year 2020 budget was $50.47 billion.[174] Breaking this down to the primary DHS components involved with maritime homeland security finds that approximately $21 billion was allocated to the USCG and CBP for operations and support.[175] In addition, DHS funded $1.7 billion in preparedness grants in fiscal year 2019. Many more agencies contribute to homeland security writ large, in large and small ways, so the decision was made that, for this effort, we would use the budget allocation figures provided by DHS as a consistent baseline for funding levels. Given the operating and support costs and the grant programs, the total is about $23 billion per year. Assuming that other agencies are contributing as well, we are comfortable projecting that approximately $25 billion per year is spent by the U.S. government on maritime homeland security.

Determining the risk of a maritime terror attack in the United States is an important element of this effort and sheds light on the decision-making process and influences on policymakers. There is very little hard data on the risk of a terrorist attack on U.S. maritime infrastructure. The MSRAM contains a database with 17,500 risk assessments of port

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[171] Heeley, *Counterterrorism Spending*; Nowrasteh, "Counterterrorism Spending"; John E. Mueller and Mark G. Stewart, "Evaluating Counterterrorism Spending," *Journal of Economic Perspectives* 28, no. 3 (August 2014): 237–48, https://doi.org/10.1257/jep.28.3.237.

[172] Heeley, *Counterterrorism Spending*, 11.

[173] Mueller and Stewart, *Responsible Counterterrorism Policy*, 4.

[174] Painter, *Appropriations: FY2020*.

[175] Painter, 11, 13.

infrastructure.[176] Ted Lewis notes that while the tool has many powerful features, it is not capable of predicting impacts on the entire MTS. He also found that the vulnerability and risk estimates fall within a "near-perfect bell curve with a mean of 24% . . . as perfect as monkeys throwing darts at the 24% mark on a plot."[177] He goes on to note that "when MSRAM data are binned to obtain the exceedance probability . . . it becomes clear that ports are not high risk."[178] In his estimation, he would place U.S. ports in the low-risk category.

In 2010, the National Academies of Science reported that DHS risk analysis and capabilities were subpar, and the academies could not find any methodology that supported risk assessments that supported resource allocation decisions regarding counterterrorism efforts. The report also noted that the risk models used for natural disasters were "near state of the art . . . based on extensive data, have been validated empirically, and appear well suited to near term decision needs."[179] The findings essentially say that billions of dollars were spent without associating funds with adequate risk, vulnerability, and threat assessments.

A look at the influence behind the decision-making rationale provides many theories on the allocation of resources to counterterrorism and why this trend continues despite no apparent tangible maritime security threat. Much has been said regarding the catastrophic events of September 11, 2001, and the scar it placed on the psyche of many Americans. No politicians appear willing to break the cycle of embracing a perceived threat, and certainly the military–industrial complex, think tanks, and armies of consultants who want to see their livelihoods protected would not want to intentionally alter the status quo. Mueller and Stewart note, "Terrorism in the United States since 9/11 has been not only sporadic (and rare), but effectively random."[180] They plainly state that "objectively

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[176] Downs, "Maritime Security Risk Analysis Model."

[177] Ted Lewis, *Bak's Sandpile: Strategies for a Catastrophic World* (Agile Research and Technology, 2011), 59.

[178] Lewis, 60.

[179] Mueller and Stewart, *Responsible Counterterrorism Policy*, 12.

[180] Mueller and Stewart, *Public Opinion and Counterterrorism Policy*, 8.

speaking, there is little reason to fear terrorism."[181] In spite of no terror attacks or terror plots publicly released in the domestic maritime domain, we continue to embrace an unspecified threat and take great effort to counter it—whatever "it" may be. The public continues to worry and fret over possibilities, however remote, of visceral terror acts, and those who should know better do little to assuage these fears. Mueller and Stewart sum it up succinctly: "Americans have bought into the terrorism fear, but at the same time . . . a great many have remained substantially unmoved by warnings about global warming—even in the face of authoritative, or seemingly authoritative, warnings that sometimes are of apocalyptic proportions."[182] Therein lies the heart of the issue—how to, as Friedman describes it, "fight the overreaction and desire to excessively fear terrorism and demand overwrought policy responses."[183] He calls for better communications and a reliance on science to develop strategies and allocation decisions.

Climate science has been providing detailed analyses and data-driven projections for many decades. As computing capabilities increase, collection tools become more plentiful and precise, and as more data are gathered and modeled, scientists gain increased knowledge in the changes they are measuring. Moreover, based on studies measuring the accuracy of earlier predictions, they generally gain confidence in predictions. This includes earlier projections made with limited data and current projections being made about future events.[184] Scientists peering into the future naturally are hesitant to make precise predictions, whether it be temperature rise, melting ice sheets, or sea level rise. Due to the large sample size—Earth—and the many unknown factors such as greenhouse gas emission rates and global temperature rise, they consistently provide a range of predictions that may or may not occur, depending on many interrelated variables. The range of predictions provide for the scientific accounting of variations and provide cover for policymakers to base assumptions on a data point somewhere within the predicted range. But as they often do, facts tend to get in the way. The month of January 2020 saw the

[181] Mueller and Stewart, 9.

[182] Mueller and Stewart, 25.

[183] Friedman, "Managing Fear," 97.

[184] Roberts, "Scientists Have Gotten Predictions of Global Warming Right."

highest global temperatures on record, and the years 2014–2019 were the six warmest years on record. In addition, in early February 2020, a record temperature of 65 degrees was recorded in the Antarctic, roughly the same temperature as downtown Los Angeles that day.[185]

Comparing the approaches of the studies involving the Ports of Virginia and San Diego provides similarities and important contrasts in methodology, planning factors, and public awareness while setting the stage for future successful or unsuccessful mitigation and resource allocation decisions. Both assessments provide consistent definitions of maritime infrastructure and similar methodologies to determine what infrastructure will be at risk and where it is located. The mapping tools and NOAA prediction models provide straightforward projections for inundation, and the ports have developed detailed assessments of the infrastructure at risk and its value. They also include economic losses that will affect local and regional gross domestic product, although the tidewater area at the Port of Virginia includes a focus on residential real estate. This appears to be because far more houses, structures, and land will be affected by sea level rise in Virginia than in San Diego. This certainly adds to projected loss values but hinders a straightforward comparison of the two areas.

The two greatest distinctions between these regions are the sea level rise predictions used to make calculations and public influence on the studies. San Diego used RCP 8.5 as the future baseline influencing future sea level rise and intentionally selected this model to provide a current worst-case scenario so that planners would have targets for developing adaptation and mitigation strategies. The authors note that using this model provides some risk of variation, but they also tacitly acknowledge that the models could be wrong and that sea level rise could be far worse and longer lasting than the year 2100 horizon. The San Diego study also incorporated public awareness campaigns and public lands, both important factors in convincing a doubting public of the efficacy and value of the report.

[185] John King, "Record Warm Day in Antarctica Is a Climate Warning," *San Francisco Chronicle*, February 7, 2020, https://www.sfchronicle.com/opinion/lastword/article/Last-Word-Record-warm-day-in-Antarctica-is-a-15039439.php.

The Port of Virginia's assessment, however, took a different approach, particularly in working with the public and local communities. It attempted to use existing models but abandoned them when they appeared to be too complex.[186] While they did initially plan to use higher predictions for sea level rise in case studies on specific communities, several planning departments in the local municipalities expressed concern that using higher numbers and shorter timeframes "portrayed sea level rise elevations that exceeded those under current use by those cities, and in particular exceeded levels they used to address sea level rise planning with their constituents."[187] The working group acquiesced to the requests by the cities and modified its predictions for sea level rise to "include ranges acceptable to all participating cities, and to remove discussion of timeframes for specific scenario events."[188] The working group provided its best estimates for sea level rise based on scientific analysis and deductions and then changed those predictions to accommodate local municipalities that were more concerned about appearances and public perception than scientific modeling. In contrast, there were no indications of public reaction driving assessment decisions in the San Diego report.

In real dollar terms, both potential infrastructure vulnerability and economic losses were factored into both regional assessments. There is currently no record of successful or planned maritime terrorism in the United States, and this has been consistent for nearly 60 years. As previously noted, estimates of annual counterterrorism spending in the United States are consistently about $100 billion per year with more than $25 billion focused on maritime homeland security. Even if this spending level begins to taper off in the coming decades, trillions of dollars will likely be spent on counterterrorism without dynamic leadership and a public willing and ready to accept changes to policies. Projected losses from sea level rise in just the Ports of Virginia and San Diego alone exceed $90 billion as previously noted. These are just two ports. Applying the Becker et al. model nationwide, the cost of raising the top 100 ports six feet and rebuilding infrastructure would fall between

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[186] Emily E. Steinhilber et al., *Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project: Phase 2 Report* (Norfolk, VA: Old Dominion University, 2016), 27.

[187] Steinhilber et al., 28.

[188] Steinhilber et al., 28–29.

$57 billion and $78 billion.[189] These figures are admittedly one-sided and highly variable and do not include economic losses and many other factors. But as a starting point for cost estimations, they provide a base on which to build.

In sum, by the year 2100, with a sea level rise as predicted in RCP 8.5, the top 100 ports could experience approximately $60 billion to $80 billion in costs to refurbish port facilities, with an untold number of economic losses and localized damages, but likely in the range of trillions of dollars. This estimate is solely based on sea level rise predictions and does not factor in social impacts, loss of housing, real estate depreciation, insurance losses, and additional losses from higher tides and storm surges that often accompany natural hazards. The numbers—even the lower-end projections—indicate tremendous risk and vulnerability to maritime ports and infrastructure, the national economy, and national defense.

B. RECOMMENDATIONS

Clearly, sea level rise can become a weapon of mass destruction. Given the threat history of maritime terrorism in the United States and the growing data supporting sea level rise predictions, the time is right, and the need is real to conduct a risk and vulnerability assessment comparing the costs and benefits of continuing to focus on the low-probability, high-consequence threat of maritime terrorism and shifting the focus to the high-consequence, high-probability threats from sea level rise.

The wide variance found in regional approaches to mitigating sea level rise underscores the need for determined leadership and steady approaches in dealing with the impacts of a changing climate. Federal engagement would provide significant resources and opportunities to lead in a consistent manner nationwide. The U.S. government sets standards through policies and regulations for regional and local entities to follow in nearly every aspect of governance. The same could be true for infrastructure adaptation and mitigation policies and practices in the future. This would require a refocusing of attention

[189] Becker, Hippe, and Mclean, "Cost and Materials Required to Retrofit US Seaports," 12.

from maritime homeland security to climate change adaptation, but it could certainly incorporate a phased-in approach in the coming years.

The United States should also lead in the global effort to reduce greenhouse gas emissions. As one of the largest contributors to current emissions, rejoining the worldwide effort to combat emissions would benefit both the environment and the economy as other countries are shifting their focus to renewable energy sources. The United States is at risk of being left behind in terms of technological development in this growing field.

The United States should also embrace the notion that climate change is a very real threat to our way of life. When the government takes actions such as rolling back fuel economy standards on vehicles, it sends a clear message that it is not taking climate change seriously.[190] When it specifically limits climate change projections to a 20-year window, it disregards the long-term consequences previously described, in essence trading future prospects for current wealth.[191] The GAO recommends that future infrastructure development include climate change considerations led by the federal government. Imposing standards for infrastructure development that circumvent or disregard long-established environmental policies, which have specifically required considering impacts on the climate, ignores expert opinions and findings, and most likely does more harm than good.[192]

The government is one facet of policy development and tends to overreact to terrorism. The private sector is also at risk in its thinking and approach. A recent report

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[190] Nsikan Akpan, "What Trump's Plan to Roll Back Fuel-Economy Standards Means for Your Wallet and the Environment," PBS NewsHour, August 2, 2018, https://www.pbs.org/newshour/nation/what-trumps-plan-to-roll-back-fuel-economy-standards-means-for-your-wallet-and-the-environment.

[191] Yasmin Tayag, "Trump's Ban on Climate Predictions beyond 2040 Forgets about One Key Factor," Inverse, May 29, 2019, https://www.inverse.com/article/56238-trump-climate-change-stifles-predictions-beyond-2040.

[192] Lisa Friedman, "Trump Rule Would Exclude Climate Change in Infrastructure Planning," *New York Times*, January 3, 2020, https://www.nytimes.com/2020/01/03/climate/trump-nepa-climate-change.html; David C. Trimble, *Climate Change: Future Federal Adaptation Efforts Could Better Support Local Infrastructure Decision Makers*, GAO-13-242 (Washington, DC: Government Accountability Office, April 2013), https://www.hsdl.org/?view&did=736500.

noted that U.S. ports are asking for $4 billion in security upgrades.[193] There is very little mention of climate change mitigation receiving this attention. Where attention rises to future scenarios, approaches are disjointed and, as noted in the Port of Virginia example, are subject to the whims of local needs that can provide a negative influence on policies and actions. This, too, begs for consolidated standards and leadership from the federal level.

This effort focused on sea level rise only—it did not include other catastrophic events such as the increased chance of larger storms, hurricanes, storm surge, flooding, and high tides associated with climate change and sea level rise that will significantly affect local inundation. We strictly examined sea level rise in terms of global mean rates and applied them to two regions. In addition, the focus on maritime port infrastructure has intentionally ignored privately owned property and real estate and the social and economic impacts to sea level rise in coastal communities due to the breadth and scale of the issues. One study indicates that approximately 630 million people worldwide will live on land that is at great risk of inundation by the year 2100.[194] The data continue to provide evidence that the path forward contains risk and uncertainty, but the trends are not positive. As this study was in its concluding phases, Arctic temperatures spiked to a record high. In February 2020, the temperature was 65 degrees Fahrenheit—warmer than downtown Los Angeles that day.[195] We owe it to ourselves and future generations to sustain a keen focus on climate change and the threats posed by nature's weapon of mass destruction.

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[193] "U.S. Ports Want $4 Billion to Enhance Security," Maritime Executive, January 28, 2019, https://www.maritime-executive.com/article/u-s-ports-want-4-billion-to-enhance-port-security.

[194] Pippa Stevens, "Study Says 630 Million Could Be Living below Projected Flood Levels by 2100," CNBC, October 29, 2019, https://www.cnbc.com/2019/10/29/study-says-630-million-could-be-below-projected-flood-levels-by-2100.html.

[195] King, "Record Warm Day in Antarctica Is a Climate Warning."

LIST OF REFERENCES

A., Cameron. “Hampton Roads Military Bases.” *Military Town Advisor* (blog), November 7, 2016. https://www.militarytownadvisor.com/blog/2016/11/7/202/hampton-roads-military-bases/.

Akpan, Nsikan. “What Trump’s Plan to Roll Back Fuel-Economy Standards Means for Your Wallet and the Environment.” PBS NewsHour, August 2, 2018. https://www.pbs.org/newshour/nation/what-trumps-plan-to-roll-back-fuel-economy-standards-means-for-your-wallet-and-the-environment.

Al-Ghussain, Loiy. “Global Warming: Review on Driving Forces and Mitigation.” *Environmental Progress & Sustainable Energy* 38, no. 1 (January/February 2019): 13–21. https://doi.org/10.1002/ep.13041.

Atkinson, Larry P., Tal Ezer, and Elizabeth Smith. “Sea Level Rise and Flooding Risk in Virginia.” *Sea Grant Law and Policy Journal* 5, no. 2 (Winter 2013): 3–14.

Becker, Austin, Ariel Hippe, and Elizabeth L. Mclean. “Cost and Materials Required to Retrofit US Seaports in Response to Sea Level Rise: A Thought Exercise for Climate Response.” *Journal of Marine Science and Engineering* 5, no. 44 (2017): 1–21. https://doi.org/10.3390/jmse5030044.

Bureau of Economic Analysis. “Gross Domestic Product.” Accessed March 2, 2020. https://www.bea.gov/data/gdp/gross-domestic-product.

Bureau of Transportation Statistics. *Transportation Statistics Annual Report 2018*. Washington, DC: Department of Transportation, 2018. https://doi.org/10.21949/1502596.

Bush, George W. *Critical Infrastructure Identification, Prioritization, and Protection*. Homeland Security Presidential Directive 7. Washington, DC: White House, 2003.

———. *The National Strategy for Maritime Security*. Washington, DC: White House, November 20, 2004. https://georgewbush-whitehouse.archives.gov/homeland/maritime-security.html.

Carrington, Damian. “Carbon Emission Release Rate ‘Unprecedented’ in Past 66M Years.” *The Guardian*, March 21, 2016. https://www.theguardian.com/environment/2016/mar/21/carbon-emission-release-rate-unprecedented-in-past-66m-years.

Center for Naval Analyses Military Advisory Board. *National Security and the Accelerating Risks of Climate Change*. Alexandria, VA: Center for Naval Analyses, 2018. https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf.

Center for Sea Level Rise. "Center for Sea Level Rise." Norfolk, VA: Old Dominion University, 2017. https://digitalcommons.odu.edu/cgi/viewcontent.cgi?article=1000&context=hripp_website.

Centers for Disease Control and Prevention. "National Center for Health Statistics Releases New Monthly Provisional Estimates on Drug Overdose Deaths." September 9, 2019, September 11, 2019. https://www.cdc.gov/nchs/pressroom/podcasts/20190911/20190911.htm.

Chappell, Bill. "U.S. National Debt Hits Record $22 Trillion." National Public Radio, February 13, 2019. https://www.npr.org/2019/02/13/694199256/u-s-national-debt-hits-22-trillion-a-new-record-thats-predicted-to-fall.

Church, John A., and Neil J. White. "Sea-Level Rise from the Late 19th to the Early 21st Century." *Surveys in Geophysics* 32, no. 4–5 (September 2011): 585–602. https://doi.org/10.1007/s10712-011-9119-1.

Climate Change Adaptation Task Force. *Climate Change Adaptation Report*. Washington, DC: Department of Homeland Security, 2010. https://www.hsdl.org/?view&did=4324.

CNN. "US Aircraft Carriers Fast Facts." June 13, 2019. https://www.cnn.com/2013/08/09/us/u-s-aircraft-carriers-fast-facts/index.html.

Connolly, Matt. "Hampton Roads, Virginia and the Military's Battle Against Sea Level Rise." Briefer No. 27. Washington, DC: Center for Climate and Security, October 14, 2015.

Department of Energy. *Effect of Sea Level Rise on Energy Infrastructure in Four Major Metropolitan Areas*. Washington, DC: Department of Energy, 2014. https://www.hsdl.org/?view&did=760524.

Department of Homeland Security. "DHS Announces Funding Opportunity for Fiscal Year 2019 Preparedness Grants." April 12, 2019. https://www.dhs.gov/news/2019/04/12/dhs-announces-funding-opportunity-fiscal-year-2019-preparedness-grants.

———. "HIFLD Open Data." Accessed September 19, 2019. https://hifld-geoplatform.opendata.arcgis.com/.

———. *NIPP 2013: Partnering for Critical Infrastructure Security and Resilience*. Washington, DC: Department of Homeland Security, 2013. https://www.cisa.gov/sites/default/files/publications/national-infrastructure-protection-plan-2013-508.pdf.

———. *Transportation Sector-Specific Plan: Maritime Modal Annex*. Washington, DC: Department of Homeland Security, 2007. https://www.hsdl.org/?abstract&did=474334.

Downs, Brady. "Maritime Security Risk Analysis Model (MSRAM)." Center for Homeland Defense and Security, June 7, 2008. Video, 24:22. https://www.chds.us/ed/items/312.

Eggleston, Jack, and Jason Pope. *Land Subsidence and Relative Sea-Level Rise in the Southern Chesapeake Bay Region*. U.S. Geological Survey Circular 1392. Reston, VA: U.S. Geological Survey, 2013. https://pubs.usgs.gov/circ/1392/pdf/circ1392.pdf.

Friedman, Benjamin H. "Managing Fear: The Politics of Homeland Security." *Political Science Quarterly* 126, no. 1 (Spring 2011): 77–106. https://www.jstor.org/stable/23056915.

Friedman, Lisa. "Trump Rule Would Exclude Climate Change in Infrastructure Planning." *New York Times*, January 3, 2020. https://www.nytimes.com/2020/01/03/climate/trump-nepa-climate-change.html.

Gibson, Gena, Robert Milnes, Matthew Morris, and Nikolas Hill. "Shipping Infrastructure." Technology Brief T17. Energy Technology Network, June 2011. https://iea-etsap.org/E-TechDS/PDF/T17_Shipping_Infrastructure_v4_final_gs.pdf.

Hall, John A., Stephen Gill, Jayantha Obeysekera, William V. Sweet, Kevin Knuuti, and John Marburger. *Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide*. Alexandria, VA: Strategic Environmental Research and Development Program, April 2016.

Hausfather, Zeke, Henri Drake, Tristan Abbott, and Gavin Schmidt. "Evaluating the Performance of Past Climate Model Projections." *Geophysical Research Letters* 47, no. 1 (2020). https://doi. org/10.1029/2019GL085378.

Hay, C. C., E. Morrow, R. E. Kopp, and J. X. Mitrovica. "Probabilistic Reanalysis of Twentieth-Century Sea-Level Rise." *Nature* 517 (2015): 481–84. https://doi.org/doi:10.1038/nature14093.

Heeley, Laicie. *Counterterrorism Spending: Protecting America While Promoting Efficiencies and Accountability*. Washington, DC: Stimson Group, May 2018.

Hildebrandt, Peter. “New Gantry Cranes for the Virginia Port Authority.” *Wire Rope & News Technology*, August 2019. https://www.wireropenews.com/news-201909-Konecranes.html.

Hubbard, Douglas. *The Failure of Risk Management: Why It’s Broken and How to Fix It*. Hoboken, NJ: John Wiley and Sons, 2009.

Isle of Wight Department of Economic Development. “Port of Virginia.” Accessed February 24, 2020. https://www.insidetheisle.com/military-installations-major-employers-ports/.

Jiang, Xinyu, Nobuhito Mori, Hirokazu Tatano, and Lijiao Yang. “Simulation-Based Exceedance Probability Curves to Assess the Economic Impact of Storm Surge Inundations Due to Climate Change: A Case Study in Ise Bay, Japan.” *Sustainability* 11, no. 4 (January 2019). https://doi.org/10.3390/su11041090.

King, John. “Record Warm Day in Antarctica Is a Climate Warning.” *San Francisco Chronicle*, February 7, 2020. https://www.sfchronicle.com/opinion/lastword/article/Last-Word-Record-warm-day-in-Antarctica-is-a-15039439.php.

Lepore, Brian J. *Climate Change Adaptation: DoD Can Improve Infrastructure Planning and Processes to Better Account for Potential Impacts*. GAO-14-446. Washington, DC: Government Accountability Office, 2014. https://www.hsdl.org/?view&did=755390.

Lewis, Ted. *Bak’s Sandpile: Strategies for a Catastrophic World*. Agile Research and Technology, 2011.

———. *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*. Hoboken, NJ: Wiley-Interscience, 2006.

Lindsey, Rebecca, and LuAnn Dahlman. “Climate Change: Global Temperature.” National Oceanic and Atmospheric Administration, January 16, 2020. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

Linkov, Igor, and Todd S. Bridges, eds. *Climate: Global Change and Local Adaptation*. Dordrecht, Netherlands: Springer, 2011. https://doi.org/10.1007/978-94-007-1770-1.

Maritime Administration. “Maritime Transportation System (MTS).” Accessed March 2, 2020. https://www.maritime.dot.gov/outreach/maritime-transportation-system-mts/maritime-transportation-system-mts.

Maritime Executive. “U.S. Ports Want $4 Billion to Enhance Security.” January 28, 2019. https://www.maritime-executive.com/article/u-s-ports-want-4-billion-to-enhance-port-security.

Maurer, Diana. *DoD Needs to Assess Risk and Provide Guidance on Use of Climate Projections in Installation Master Plans and Facilities Designs*. GAO-19-453. Washington, DC: Government Accountability Office, June 12, 2019. https://www.gao.gov/assets/700/699679.pdf.

Meyer, Robinson. "A Terrifying Sea-Level Prediction Now Looks Far Less Likely." *The Atlantic*, January 4, 2019. https://www.theatlantic.com/science/archive/2019/01/sea-level-rise-may-not-become-catastrophic-until-after-2100/579478/.

Mueller, John E., and Mark G. Stewart. "Evaluating Counterterrorism Spending." *Journal of Economic Perspectives* 28, no. 3 (August 2014): 237–48. https://doi.org/10.1257/jep.28.3.237.

———. *Public Opinion and Counterterrorism Policy*. Washington, DC: Cato Institute, February 20, 2018. https://www.cato.org/publications/white-paper/public-opinion-counterterrorism-policy.

———. *Responsible Counterterrorism Policy*. Policy Analysis No. 755. Washington, DC: Cato Institute, September10, 2014. https://www.cato.org/sites/cato.org/files/pubs/pdf/pa755.pdf.

National Aeronautics and Space Administration. "Global Temperature." Accessed January 31, 2020. https://climate.nasa.gov/vital-signs/global-temperature.

National Consortium for the Study of Terrorism and Responses to Terrorism. "Jihadist Terrorist Plots in the United States." College Park: University of Maryland, 2017.

National Oceanic and Atmospheric Administration. "Sea Level Rise Viewer." Accessed September 19, 2019. https://coast.noaa.gov/digitalcoast/tools/slr.html.

Nauels, Alexander, Malte Meinshausen, Matthias Mengel, Katja Lorbacher, and Tom M. L. Wigley. "Synthesizing Long-Term Sea Level Rise Projections—The MAGICC Sea Level Model v2.0." *Geoscientific Model Development* 10, no. 6 (2017): 2495–2524. https://doi.org/10.5194/gmd-10-2495-2017.

Nicholls, R. J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, and R. MuirWood. "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes, Exposure Estimates." Paris: Organisation for Economic Development and Cooperation, November 19, 2008.

Nowrasteh, Alex. "Counterterrorism Spending." *Cato at Liberty* (blog), May 25, 2018. https://www.cato.org/blog/counter-terrorism-spending.

Nunez, Christina. "Sea Level Rise, Explained." *National Geographic*, February 19, 2019. https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/.

Pachauri, Rajendra K., and Leo A. Meyer. *Climate Change 2014: Synthesis Report*. Geneva: Intergovernmental Panel on Climate Change, 2015.

Painter, William L. *Department of Homeland Security Appropriations: FY2020*. CRS Report No. R46113. Washington, DC: Congressional Research Service, January 21, 2020. https://crsreports.congress.gov.

Pearson, Roy L., and K. Scott Swan. *The Fiscal Year 2018 Impacts Virginia Economic Impacts of the Port of Virginia*. Williamsburg, VA: College of William & Mary, November 18, 2019. http://www.portofvirginia.com/wp-content/uploads/2019/11/THE-FISCAL-YEAR-2018-VIRGINIA-ECONOMIC-IMPACTS-OF-THE-PORT-OF-VIRGINIA.pdf.

Peng, Binbin, and Jie Song. "A Case Study of Preliminary Cost-Benefit Analysis of Building Levees to Mitigate the Joint Effects of Sea Level Rise and Storm Surge." *Water* 10, no. 2 (2018). https://doi.org/10.3390/w10020169.

Phillips, Erica E. "At the Water's Edge, Seaports Are Slowly Bracing for Rising Ocean Levels." *Wall Street Journal*, February 11, 2019. https://www.wsj.com/articles/at-the-waters-edge-seaports-are-slowly-bracing-for-rising-ocean-levels-11549882801.

Pörtner, Hans-Otto, Debra C. Roberts, Valérie Masson-Delmotte, Panmao Zhai, Melinda Tignor, Elvira Poloczanska, Katja Mintenbeck, et al. *Special Report on the Ocean and Cryosphere in a Changing Climate*. New York: United Nations, 2019. https://www.ipcc.ch/srocc/.

Port of San Diego. *Sea Level Rise Vulnerability Assessment & Coastal Resiliency Report*. San Diego: Port of San Diego, June 2019.

Port of Virginia. "Home Page." Accessed March 3, 2020. http://www.portofvirginia.com/.

President's Commission on Critical Infrastructure Protection. "Acting Now to Protect the Future." In *Critical Foundations: Protecting America's Infrastructures*. Washington, DC: President's Commission on Critical Infrastructure Protection, October 1997. https://fas.org/sgp/library/pccip.pdf.

———. "Appendix B: Glossary." In *Critical Foundations: Protecting America's Infrastructures*. Washington, DC: President's Commission on Critical Infrastructure Protection, October 1997. https://fas.org/sgp/library/pccip.pdf.

Pumphrey, Carolyn, ed. *Global Climate Change: National Security Implications*. Carlisle, PA: Strategic Studies Institute, 2008. https://doi.org/10.21236/ADA480687.

Reinhart, John F. “Charting a Course for Success.” Presentation at the Port of Virginia, November 12, 2014. http://www.virginiadot.org/2014_Governor_Conference/documents/Charting_a_Course_for_Success_VAPort_John_Reinhart.pdf.

Roberts, David. “Scientists Have Gotten Predictions of Global Warming Right since the 1970s.” Vox, December 4, 2019. https://www.vox.com/energy-and-environment/2019/12/4/20991315/climate-change-prediction-models-accurate.

San Diego Tourism Authority. “Military Information.” Accessed March 3, 2020. https://www.sandiego.org/articles/military/military-information.aspx.

Sandler, Todd, and Walter Enders. *Economic Consequences of Terrorism in Developed and Developing Countries: An Overview*. Washington, DC: World Bank, September 2005. http://wenders.people.ua.edu/uploads/2/6/3/8/26382715/econ_consequences_revised.pdf.

Select USA. “Logistics and Transportation Spotlight.” Accessed September 19, 2019. https://www.selectusa.gov/logistics-and-transportation-industry-united-states.

Shumake, Jon. “Study Finds U.S. Ports Contributed $5.4 Trillion to GDP.” *American Shipper*, March 20, 2019.

Skeptical Science. “How Much Will Sea Levels Rise in the 21st Century?” Accessed February 18, 2020. https://skepticalscience.com/sea-level-rise-predictions-basic.htm.

Steinhilber, Emily E., Maura Boswell, Carol Considine, and Larry Mast. *Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project: Phase 2 Report*. Norfolk, VA: Old Dominion University, 2016.

Stevens, Pippa. “Study Says 630 Million Could Be Living below Projected Flood Levels by 2100.” CNBC, October 29, 2019. https://www.cnbc.com/2019/10/29/study-says-630-million-could-be-below-projected-flood-levels-by-2100.html.

Sweet, William V., Robert E. Kopp, Christopher P. Weaver, Jayantha Obeysekera, Radley M. Horton, E. Robert Thieler, and Chris Zervas. *Global and Regional Sea Level Rise Scenarios for the United States*. Silver Spring, MD: National Oceanic and Atmospheric Administration, January 2017.

Tayag, Yasmin. “Trump’s Ban on Climate Predictions beyond 2040 Forgets about One Key Factor.” Inverse, May 29, 2019. https://www.inverse.com/article/56238-trump-climate-change-stifles-predictions-beyond-2040.

Taylor, Bruce, and Pat Kaufman. “Protecting America’s Ports.” *National Institute of Justice Journal*, no. 262 (March 2009). https://nij.ojp.gov/topics/articles/protecting-americas-ports.

Trimble, David C. *Climate Change: Future Federal Adaptation Efforts Could Better Support Local Infrastructure Decision Makers*. GAO-13-242. Washington, DC: Government Accountability Office, April 2013. https://www.hsdl.org/?view&did=736500.

Trump, Donald. *National Security Strategy of the United States of America*. Washington, DC: White House, 2017. https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.

United Nations. "The Paris Agreement." Accessed March 3, 2020. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

U.S. Census Bureau. "Home Page." Accessed March 3, 2020. https://www.census.gov/en.html.

U.S. Global Change Research Program. *Fourth National Climate Assessment*. Vol. 2. Washington, DC: U.S. Government Printing Office, 2018. https://nca2018.globalchange.gov.

Van Houtven, George, Brooks Depro, Daniel Lapidus, Justine Allpress, and Benjamin Lord. *Costs of Doing Nothing: Economic Consequences of Not Adapting to Sea Level Rise in the Hampton Roads Region*. Research Triangle Park, NC: RTI International, November 2016. http://resilientvirginia.org/wp-content/uploads/2017/04/20161116-hampton-roads-costs-of-doing-nothing-report.pdf.

Wallischeck, Eric York. *ICS Security in Maritime Transportation: A White Paper Examining the Security and Resiliency of Critical Transportation Infrastructure*. Washington, DC: Department of Transportation, 2013. https://www.hsdl.org/?abstract&did=743534.

Wasp, Valli A. "Will Climate Change the Future of Homeland Security?" Master's thesis, Naval Postgraduate School, 2016. https://www.hsdl.org/?abstract&did=796633.

Wilkes, James, and Gray Page. "Rethinking Maritime Security." Safety 4 Sea, October 25, 2017. https://safety4sea.com/rethinking-maritime-security-2/.

Woetzel, Jonathan, Dickson Pinner, Hamid Samandari, Hauke Engel, Mekala Krishnan, Brodie Boland, and Carter Powis. *Climate Risk and Response: Physical Hazards and Socioeconomic Impacts*. San Francisco: McKinsey Global Institute, January 2020.

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