The Good, the Bad, and the Robust: Climate Change Adaptation Choices for the Port of Rotterdam, Port of San Diego, and Naval Base Kitsap – Bremerton

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Abstract

THE GOOD, THE BAD, AND THE ROBUST: CLIMATE CHANGE ADAPTATION CHOICES FOR THE PORT OF ROTTERDAM, THE PORT OF SAN DIEGO, NAVAL BASE KITSAP – BREMERTON
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Due to the inevitability of climate change, long-term adaptation planning is now a necessary facet of infrastructure planning. The projected impacts of sea level rise on coastal infrastructure are particularly dramatic. Although the U.S. Navy has publicly recognized the potential impacts to Navy infrastructure from climate change, adequate guidance has not been provided to assist Navy infrastructure planners with planning for an uncertain future.

This thesis provides a comparative analysis of climate change adaptation choices for the Port of Rotterdam, Port of San Diego, and Naval Base Kitsap – Bremerton. Adaptation planning by ports is the focus of this project due to the similarities between the functions and infrastructure of military and commercial ports. The overarching research intent is to analyze the robustness of current adaptation planning for ports, identify robust yet practical planning choices, and construct a functional adaptation planning framework for use by Navy infrastructure planners.

This project analyzed six key adaptation choices for the ports from a robustness perspective: climate change scenarios, decision support tools, adaptation strategy, adaptation actions, adaptation funding sources, and adaptation planning timeframe. Each of the ports' adaptation choices was evaluated using a literature-based methodology, the results of which informed recommendations of the most robust planning choices the U.S. Navy could practically make.

The comparative study found the most robust yet practical climate scenario is use a series of scenarios as decision thresholds for flexible, adaptive decision-making. The most robust decision support tool is a combination of methods which are tolerant of uncertainty, such as the reasonable person decision path and resilience planning. The recommended adaptation strategy is a combination of protection, accommodation, and rebuild and recover approaches. A complete list of recommended adaptation actions is location-dependent, though certain actions are robust regardless of location and rate and extent of climate change. Practical, robust recommendations for adaptation planning timelines and financing are 2100 and multiple types of federal funding, respectively. Overall, a planning framework based upon the robustness of adaptation choices made for ports is a promising approach to climate change adaptation planning.

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List of Acronyms

CNA………………………. Center for Naval Analysis

DOD ……………………....... Department of Defense

DON……………………….. Department of the Navy

FY…………………………. Fiscal year

GHG………………………. Greenhouse gas

IPCC………………………. Intergovernmental Panel on Climate Change

IPL………………………… Integrated priority list

NAP………………………. Normaal Amsterdams Peil

NAVFAC…………………. Naval Facilities Engineering Command

NBK……………………… Naval Base Kitsap – Bremerton

NFESC……………………. Naval Facilities Engineering Service Center

NOAA…………………….. National Oceanographic and Atmospheric Administration

PSNS……………………… Puget Sound Naval Shipyard

PWD………………………. Public Works Department

RDM………………………. Robust Decision Making

RPDP……………………… Reasonable Person Decision Path

SDCC……………………… San Diego Convention Center

SERDP…………………….. Strategic Environmental Research and Development Program

UKCIP……………………. United Kingdom Climate Impacts Programme

USACE……………………. United States Army Corps of Engineers

UPSD………………………Unified Port of San Diego

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1. Introduction

The United States Navy is the most powerful naval force in the world today[1] (Mizokami 2014). Charged with defending freedom of the seas, deterring aggression, and, when necessary, winning wars, the U.S. Navy is a formidable maritime force (U.S. Navy 2014). Such a force seems unbeatable in a conventional fight (and, some might go so far to argue, largely unsinkable).

The trouble is, the Navy is already sinking – and has been – for decades (Melillo, Richmond, and Yohe 2014, 17; IPCC 2013, 11; Van den Hurk *et al* 2014). The reason: climate change. Although American politicians continue to debate the extent to which climate change is a) occurring and b) due to human actions, the science is clear: humankind is changing the climate (IPCC 2013 and 2014; Melillo, Richmond, and Yohe 2014, 16; Anderegg *et al* 2010). These climatic changes include sea level rise, shifting weather patterns, variation in precipitation, and global warming, all of which impact the U.S. Navy's built infrastructure and the Navy's ability to perform its assigned functions (CNA 2014; NFESC 2009).

Although the U.S. Navy is impressive, it clearly cannot overcome climate change with firepower. Although Navy ships can easily rise with the ocean, the Navy's land-based infrastructure cannot so easily adjust to sea level rise,[2] global warming, and the associated effects of climate change. The only alternative is to adapt.

[1] As measured by number of ships, size of ships, and capabilities of those ships.
[2] In this paper, the term "sea level rise" refers to the relative change in mean sea level due to the combined effects of sea level rise, land uplift, and land subsidence. Within this context "sea level rise" may be positive or negative.

1.1. Study Context

1.1.1. Climate Change

Climate change is occurring on a global scale (IPCC 2013 and 2014; Melillo, Richmond, and Yohe, 2014; Van den Hurk *et al* 2014; Herring *et al* 2014). Atmospheric and oceanic temperatures are rising, glacial ice is melting, precipitation patterns are changing, and sea levels are rising. Although these changes are not unusual over millennia or even centuries, the relatively rapid pace of these changes is alarming. Greenhouse gases[3] resulting from human activity are judged "extremely likely" to have produced these substantial changes around the world, in every country and every climate (IPCC 2013, 17).

Reacting to the threat of climate change requires a two-fold response: mitigation and adaptation. Greenhouse gas (GHG) emissions must be drastically mitigated, first and foremost (IPCC 2014). Given past and current rates of greenhouse gas generation, however, climate change effects will linger for centuries (IPCC 2014; Melillo, Richmond, and Yohe 2014). Thus even with immediate, effective GHG mitigation policies on a global scale (which do not appear likely at this time), adaptation programs must also be initiated to proactively address the unavoidable effects of climate change (IPCC 2014).[4] For this project, adaptation to climate change is defined broadly to include any "adjustment to a new or changing environment which exploits beneficial opportunities or negative effects" (U.S. Global Change 2015). Actions can be "soft," such as

[3] The IPCC (2013, 11) considers the primary greenhouse gases of concern to be carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), though the definition extends to any gas which contributes to trapping of heat in the atmosphere.

[4] Although the recent climate change accord proposed in Lima, Peru appears promising, initial responses to the proposed GHG reductions appear to be along the lines of "a good start, but not enough" (Stern 2014; Roberts 2014; Upton 2014;)

purchase of flood insurance, or "hard," such as construction of wave attenuation devices to limit the impact of storm surge.

Adaptation efforts in coastal areas must include preparation for rising seas, which represents a tremendous challenge for all infrastructure constructed at or near sea level. Under worst case scenarios sea level rise will result in nearly unfathomable costs worldwide, both human and financial, if proactive adaptation measures are not taken (Nicholls *et al* 2008). Preventive measures are necessary to avoid even more costly reconstruction programs in the wake of a great waterborne calamity. The most recent catastrophic example was Hurricane Sandy, which devastated the American East Coast in November 2012 and caused an estimated $66 billion in damage (Department of Commerce 2013). In the wake of Hurricane Sandy, New York City, which alone incurred an estimated $19 billion in damage from the storm (Toro 2013), announced a $19.5 billion program to prepare the city to withstand future storms exacerbated by rising seas (Gallucci 2013).

1.1.2. U.S. Navy Responses to Climate Change

Give the inevitability of climate change, institutions and governments at all levels must mitigate greenhouse gas emissions and plan to adapt to an uncertain future (IPCC 2014; Melillo, Richmond, and Yohe, 2014). Reducing greenhouse gas emissions is already an official priority of the Navy. Among other emission reduction goals, the Navy seeks to reduce facility energy intensity[5] 30% by 2015 and 50% by 2020 (as compared to a fiscal year 2003 baseline), and produce or procure 50% of facility energy requirements from alternative sources by 2020 (CNIC

[5] Energy consumption per square foot of facility.

2014). Although the Navy is lagging slightly in facility energy savings (19.0% through 2013 vs. goal of 24%), the sea service now satisfies 26.6% of facility energy needs from renewable sources, more than halfway to their 50% goal (DOD 2014b).

Naval Facilities Engineering Command (NAVFAC) operates and maintains U.S. Navy facilities and infrastructure (NAVFAC 2012). Although NAVFAC has aggressively pursued the Navy's emission reduction goals via policy and practice, planning to adapt to climate change is not listed as a priority in NAVFAC's Fiscal Year (FY) 2013 – 2016 Strategic Plan. Neither rules or nor policy guidance have been published regarding decision-making for climate change adaptation planning for U.S. Navy coastal infrastructure.[6] As a result, planning and infrastructure choices with far-reaching effects are made regularly by NAVFAC officials without systematically considering sea level rise and other aspects of climate change, and how those changes might ultimately affect the Navy's coastal infrastructure as well as the Navy's ability to fulfill its essential functions.

1.1.3. Navy Infrastructure at Risk

U.S. Navy ports and related facilities, which comprise a key portion of the Navy's infrastructure, are necessarily located on coastlines due to the Navy's sea-based mission. Prior to the current understanding of climate change and sea level rise, coastal infrastructure was designed based on assumptions of predictable sea levels and flood plains (Moser *et al* 1990). This assumption has left Navy port infrastructure particularly vulnerable to sea level rise and extreme weather events (National Research Council 2011). As a result NAVFAC has inherent interest in protecting

[6] This is in contrast to the U.S. Army Corps of Civil Engineers Directorate of Civil Works, which in 2014 published "Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation" (USACE 2014a).

coastal infrastructure from climate change-related damage which would inhibit accomplishment of the U.S. Navy's larger mission.

1.2. Research Question

Climate change is a major challenge for NAVFAC officials, who must ensure naval facilities support accomplishment of Navy missions despite on-going climatic change. However, NAVFAC does not have a comprehensive strategy for planning for adaptation to climate change. This research project focuses on planning for climate change for U.S. Navy coastal facilities. The desired outcome is information and analysis which contributes to the development of NAVFAC climate change adaptation guidance. Such guidance is important since NAVFAC must ensure critical mission support facilities remain functional in the climate change era. The primary audience for this research project is the leadership of NAVFAC. The secondary audience is the leadership of NAVFAC public works organizations which report to NAVFAC headquarters.

This project seeks to answer the question:

> "How can the U.S. Navy most effectively plan to adapt its coastal infrastructure to climate change?"

The research question is derived directly from the first policy question identified by the Strategic Environmental Research and Development Program (SERDP)[7] in its 2013 report, *Assessing Impacts of Climate Change on Coastal Military Installations: Policy Implications*:

[7] SERDP is the Department of Defense's program for basic and applied research and advanced development in the areas of environmental science and technology (SERDP 2014). SERDP coordinates with the Department of Energy and Environmental Protection Agency as well as other government and non-government entities in executing its mandate.

"How can the DOD and the military Services best integrate climate change considerations into planning and decision processes to ensure military readiness and asset protection?"

Essentially, this study seeks to understand the *who*, *what*, *when*, *where*, *why*, and *how* of climate change adaptation planning at ports. The outcome of this understanding will be an adaptation planning framework for improving the resiliency of the Navy's coastal infrastructure to climate change. To develop the framework, the main research question and research sub-questions (framed as a series of choices) must be satisfactorily answered:[8]

1. Which climate change scenario(s) did the port choose to rely upon to make adaptation decisions?
2. Which decision support tools did the port choose to make adaptation decisions?
3. Which adaptation strategy(ies) did the port choose?
4. Which adaptation action(s) did the port choose to implement?
5. Which funding source(s) did the port choose to finance implementation of its adaptation plans?
6. Which adaptation planning timeframe timeline did the port choose?

1.3. Research Design

In general, policy makers encounter two large questions when considering climate change: what will be the climate of the future, and what should be done to adapt to that future climate? (Wardekker 2011). This thesis focuses primarily on latter question. The Department of Defense,

[8] The research sub-questions are based in part upon the planning questions posed by the USACE guidance on planning for adaptation of coastal infrastructure (2014a, 3-13).

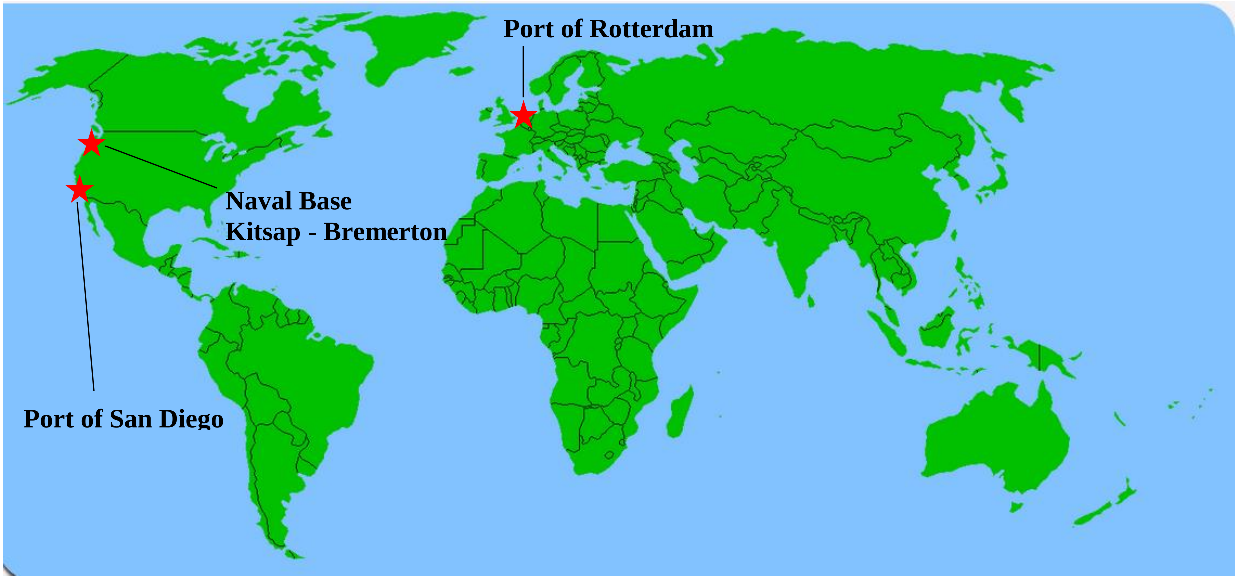
via the Strategic Environmental Research and Development Program (SERDP), has funded a host of research studies into climate change mitigation and adaptation. The research agenda includes projects which identified climate change information needs, developed decision-making frameworks, and conducted vulnerability assessments (e.g., Burks-Copes *et al* 2014; Chadwick *et al* 2014). Still, none of the SERDP research studies are comparative in nature, examining adaptation efforts by institutions with similar infrastructure to those of military facilities. In this case, the obvious counterpart to a Navy port is a commercial port. Therefore, this project seeks to gain insight into climate change adaptation planning for commercial ports, which may then be adapted to Navy purposes.

Nearly all U.S. Navy coastal infrastructure is directly or indirectly associated with a working military port. Consequently, the author studied three ports at various stages of planning for climate change adaptation in order to determine how NAVFAC can most effectively plan to adapt to the effects of climate change. By understanding what these ports have already done (or not done, as the case may be) to plan for climate change adaptation, this project seeks to derive important and useful lessons for NAVFAC policy-makers facing similar decisions.

This research project applies a comparative research methodology to three ports, two commercial and one military:

- Port of Rotterdam, The Netherlands
- Port of San Diego, California, United States
- Naval Base Kitsap – Bremerton, Washington, United States

Figure 1.1. Study locations
(Image: isghd.com 2014)



Rotterdam and San Diego were identified by Becker *et al* (2013) as exemplars of commercial ports planning to adapt to climate change. Additionally, The Netherlands was identified in a 2009 Navy white paper, *Assessing Climate Change-Related Impacts on U.S. Navy Installations Initial Decision Report*, as an being a world leader in adaptation planning. Naval Base Kitsap – Bremerton is included in this study as the Navy port closest to the author's residence in Seattle, W.A. Of the three, the Port of Rotterdam has advanced the furthest in planning for climate change, Naval Base Kitsap – Bremerton the least, and the Port of San Diego is approximately in the middle.

Each location has valuable facilities and infrastructure at risk due to sea level rise, extreme weather (e.g., storm surge), and other climate change effects. The governance structures of the commercial ports are similar, but Naval Base Kitsap – Bremerton is markedly different. Maximum projections and ranges of sea level rise through 2100 in each location also differ:

- Rotterdam: 12” to 39” (0.3 to 1.0 m) (Ministry Infrastructure 2014, 136).
- San Diego: 31” to 69” (0.78 to 1.76 m) (Hirschfeld and Holland 2012, iii).
- Naval Base Kitsap – Bremerton: 4” to 56” (0.1 to 1.43 m) (NRC 2012, 72).

1.4. Study Locations

1.4.1. Port of Rotterdam

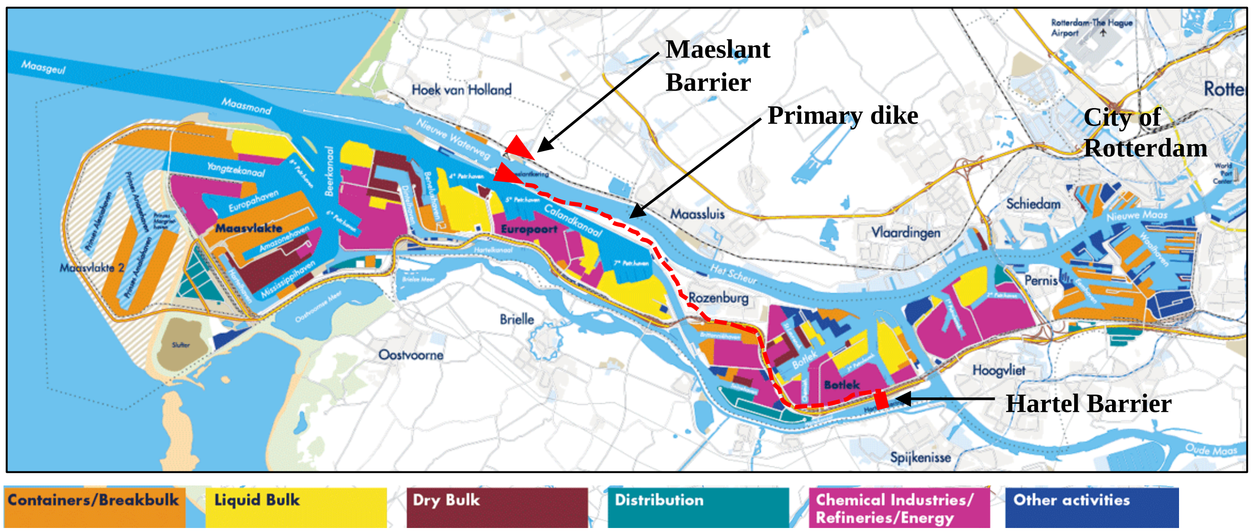
The roots of the Port of Rotterdam extend back to the 1400s (Port of Rotterdam 2013a). For centuries the port occupied a relatively small footprint in the heart of the city. Early in the 20th century the port began to grow, ultimately becoming the largest port in Europe, and one of the five biggest ports in the world (Ibid.). The port measures 26-miles in length and includes an area of more than 31,000 acres, of which 19,250 acres are land (Port of Rotterdam 2014a). Figure 1.2 illustrates the full extent of the port. The port is completely encompassed by the boundaries of the City of Rotterdam and is subject to city zoning regulations (Eisma 2014). Rotterdam is governed by an elected city council and an appointed municipal executive committee charged with management of the city’s daily affairs (Figee, Eigeman, and Hilterman 2007).

Although The Netherlands is renowned for its extensive system of dikes, the port lies entirely outside of permanent dikes (Van Peijpe *et al* 2012). Consequently the land on which the port sits has been raised over the years until elevations range from 3.5 meters to 5.5 meters NAP.[9] Approximately half of the port, generally constructed at an elevation of 3.5 meters NAP, does lie behind the closable Maeslant storm surge barrier (indicated in Figure 1.2). The barrier is

[9] Normal Amsterdam Level (NAP) (*Normaal Amsterdams Peil* in Dutch) is the vertical ordnance datum used by The Netherlands. The NAP of +0.0 meters originally corresponded to the average high tide level in Amsterdam. Since the city is no longer directly connected to the sea, NAP of +0.0 meters is preserved as a brass benchmark in Amsterdam (Gemeente Amsterdam 2014).

designed to close when ocean tides are predicted to reach 3.0 meters NAP (Deltawerken 2004).[10] A second massive structure, the Hartel flood barrier, protects the "back door" of the port against flooding. A large dike passes through the middle of the port and connects the two barriers.

Figure 1.2 Port of Rotterdam
(Image: Port of Rotterdam 2013a, 12)



In 2004 the Port of Rotterdam Authority was established as an unlisted public corporation owned by the City of Rotterdam (70% shareholder) and the national government (30% shareholder) (de Langen and Heij 2013; Port of Rotterdam 2014b).[11] The purpose of divesting the port from the city was to provide more focused management of port operations by experienced professionals rather than elected officials (Ibid.). The Port Authority rents the land from the city via a 100-year lease (Eisma 2014). The port maintains sites or terminals for oil, chemical and fuels; gas, power, coal, and biomass; steam, industrial gases, water plants, and waste processing; container

[10] The Maeslant barrier (*Maeslantkering* in Dutch) was part of the Delta Works, a massive public works program initiated by the Dutch national government after disastrous floods in 1953 (Deltawerken 2004). The Maeslant barrier, which protects the city and port of Rotterdam, opened in 1997.

[11] Prior to 2004 the port was a department within the City of Rotterdam.

terminals; bulk goods; and tank storage for oil and other products (Port of Rotterdam 2014b). Companies lease land and facilities from the Port Authority, and are responsible for protecting their leaseholds against damage from sea level rise, earthquakes, flooding, etc. (Tieman and van ‘t Noordende 2014; Eisma 2014).

Daily management of the Port of Rotterdam Authority is performed by an executive board elected by shareholders (Port of Rotterdam 2014c). The executive board is overseen by a Supervisory Board, also elected by shareholders. According to the Port’s mission statement, “The Port of Rotterdam is responsible for the development, construction, management and operation of the port and industrial area in Rotterdam and promotes the effective, safe and efficient handling of shipping in the port of Rotterdam and the offshore approaches to the port” (Port of Rotterdam 2014b).

The Port Authority is the sole entity responsible for adaptation to climate change, a view reportedly shared by Rotterdam city planners (Van Barneveld 2014). At the same time, City of Rotterdam officials feel a societal responsibility to ensure the Port of Rotterdam is prepared for the effects of climate change (Van Barneveld 2014). The Dutch national government also views the Port of Rotterdam as a national asset[12] and thus far has been receptive to arguments that the government is also responsible for adaptation at the port (Van Barneveld 2014; Eisma 2014).

Due to the overlapping responsibilities of the Port of Rotterdam Authority, City of Rotterdam, and the Dutch national government, the analysis contained within this research project will

[12] The Port of Rotterdam supports an estimated 145,000 direct and indirect jobs and 3.7% of the Dutch economy (Van den Bosch *et al* 2010, ii).

combine the plans and policies of each entity to produce a coherent picture of climate change adaptation planning at the Port of Rotterdam.

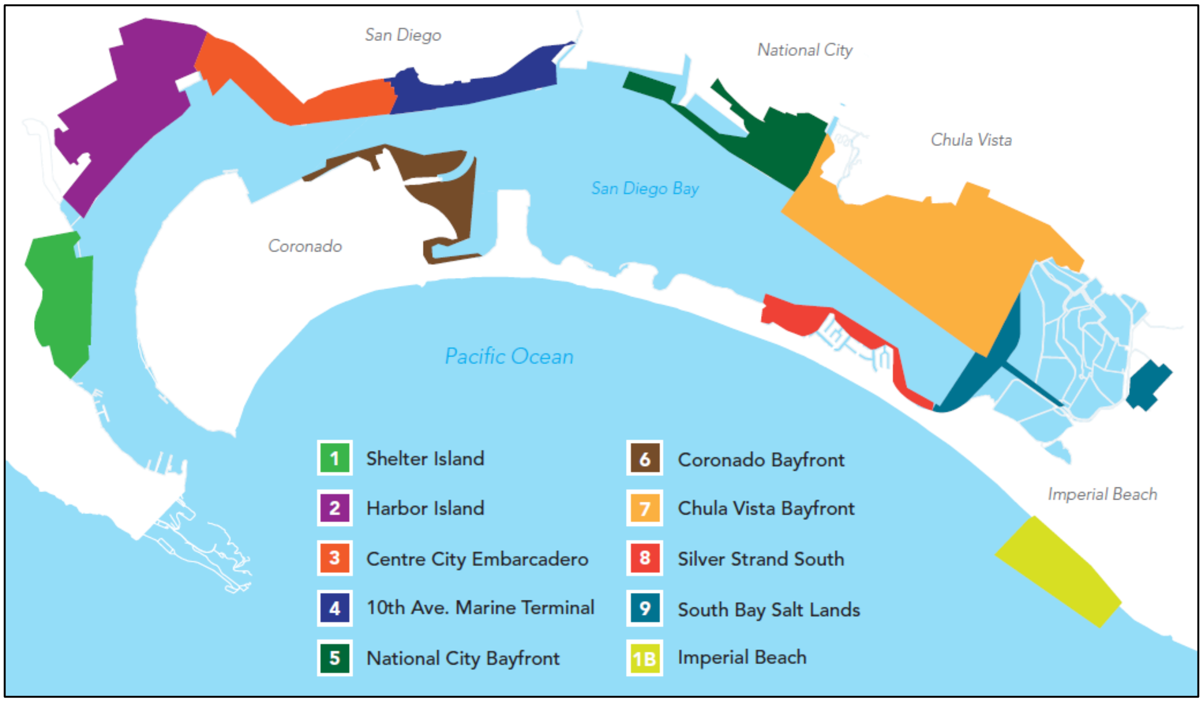
1.4.2. Port of San Diego

Although the San Diego Unified Port District[13] was created in 1962 as a public benefit corporation by the California Legislature (UPSD 2012c), the history of the port reaches back for centuries. The UPSD is overseen by a seven-member Board of Port Commissioners appointed by the city councils of the municipalities encircling San Diego Bay: San Diego, Chula Vista, Coronado, Imperial Beach and National City (Ibid.). Now the fourth largest port in California by shipping volume, the port's legal planning area includes 2,491 acres of land, 2,992 acres of water, and 33.1 shoreline miles. These totals represent approximately 37% of the tidelands and 61.3% of the shoreline miles in San Diego Bay; the other large tideland and shoreline managers are the U.S. military and the State of California (Ibid., 4).

The port includes many activities other than the traditional functions of shipbuilding and maintenance; other uses include maritime cargo, cruise ship berthing, navigation, public open space and recreation, commercial fishing, conservation, and more than 600 commercial leases and subleases (UPSD 2012c). Figure 1.3 shows the UPSD's area of planning responsibility.

[13] More commonly referred to as the Unified Port of San Diego, or simply, the Port of San Diego.

Figure 1.3. Port of San Diego planning areas
(Image: UPSD 2013a, 9)



Unsurprisingly, the Port's mission's statement is equally broad (UPSD 2015):

> "The San Diego Unified Port District will protect the Tidelands Trust resources by providing economic vitality and community benefit through a balanced approach to maritime industry, tourism, water and land recreation, environmental stewardship and public safety."

Day-to-day management of the UPSD is performed by executives hired by the Board of Port Commissioners and their supporting staff. The UPSD is subject to all applicable coastal laws and regulations implemented by the federal government and the State of California. The Port of San Diego published a climate action plan in 2012 which focused on greenhouse gas mitigation rather than adaptation to climate change. The plan did acknowledge that "the Port is responsible for planning and preparing for future impacts of climate change on its environment" (UPSD

2013a, 4). The Port's 2012-2017 Strategic Plan also called for incorporating adaptation to sea level rise and climate change into the port's long-term plans (2012, 5), helping to push the planning process forward.

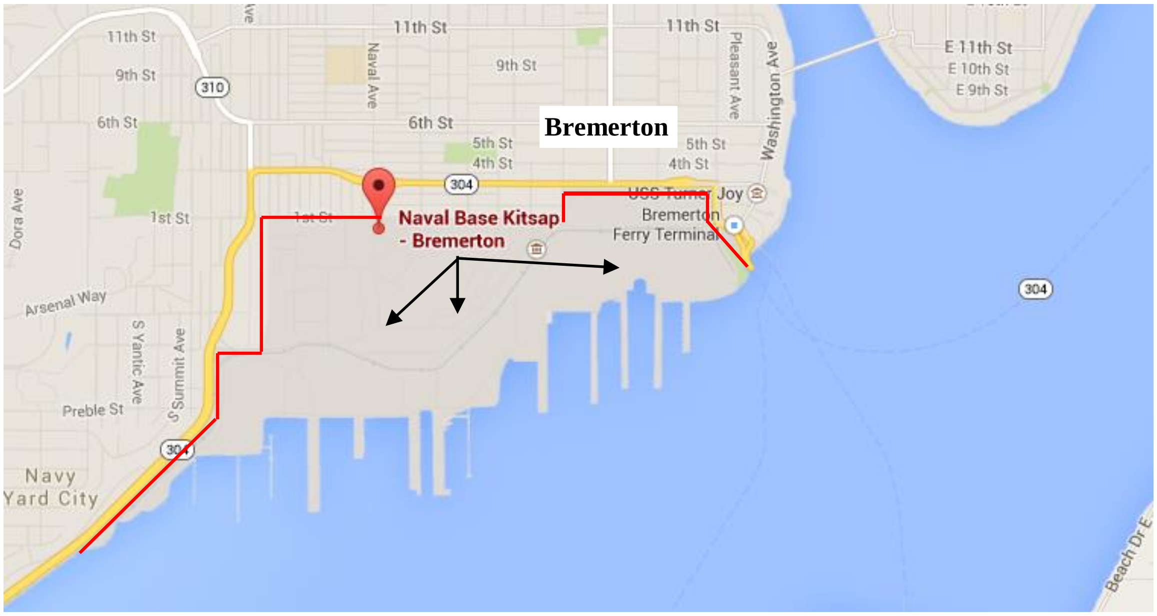
As noted above, the Port only plans for a portion of the San Diego Bay area; the U.S. military, the State of California, and the cities adjoining the bay must also plan to adapt to the effects of climate change. The focus of this research project is on the planning efforts of the port, though the adaptation planning of other entities are discussed when appropriate.

1.6.3. Naval Base Kitsap – Bremerton

Naval Base Kitsap – Bremerton (NBK) was inaugurated in 1891 as Puget Sound Naval Shipyard, the U.S. Navy's first shipyard and maintenance facility in the Pacific Northwest region (McClary 2003). Bounded by the City of Bremerton, W.A., on three sides and Sinclair Inlet on the fourth, NBK now includes 344 acres of dry land, 338 acres of submerged land, and 11,000 feet of shoreline (Ibid.). Nine piers, four mooring sites, six dry docks, and nearly 400 structures populate the base. Figure 1.4 shows the base and the City of Bremerton. Activities conducted at the base include maintenance, modernization, mooring/docking, and decommissioning of Navy ships (McClary 2003). It is also one of the four nuclear-capable Navy shipyards, and the only such shipyard on the west coast of the continental United States.[14] The U.S. Navy completely owns and manages Naval Base Kitsap – Bremerton, therefore the Navy is only obligated to follow federal law. No flood or storm control facilities, such as seawalls, dikes, or breakwaters, protect the shipyard.

[14] The next closest nuclear capable shipyard is in Pearl Harbor, H.I.

Figure 1.4. Naval Base Kitsap – Bremerton
(Image: Google Maps 2015)



Primary responsibilities for maintenance and operation of NBK:

- Naval Base Kitsap – Bremerton (NBK):
  - Supervises provision of base operating services, including facilities, environmental, safety, real estate, emergency planning, etc.
  - The "owner" of NBK and all surrounding Navy property.
- NAVFAC Public Works Department (PWD) Kitsap:
  - Responsible for utility provision and asset management of NBK facilities.[15]
  - Reports to NBK on accomplishment of responsibilities.
  - Similar in function to the public works department of a commercial port authority.

[15] A more complete list of NAVFAC planning and facility responsibilities includes: land use planning, asset management, facilities planning and project development, geospatial information and services, encroachment management, facility asset data management, real estate services, environmental programs, cultural and natural resources, facility support contracts, utilities, and energy systems (NAVFAC 2015).

- Puget Sound Naval Shipyard (PSNS) and Intermediate Maintenance Facility
    - Responsible for ship maintenance, modernization, and decommissioning.
    - A “tenant command” of Naval Base Kitsap, similar in function to a commercial company which pays a port authority for facilities and services.
    - Maintains an internal staff for PSNS facilities planning and management.

NAVFAC PWD Kitsap, as the asset manager of the shipyard, is the organization primarily responsible for planning for climate change adaptation at the local level, the focus of this project. As NAVFAC’s primary customer at the shipyard, PSNS also matters greatly in the context of decision-making for local climate change adaptation. Adaptation policy will be established at the U.S. Department of Defense and Department of the Navy level for NAVFAC PWD Kitsap to implement at the local level (Marburger 2015; Gabbard 2015). Since such policy guidance has not been given, adaptation planning at NBK has not progressed.

Although directly proximate to the City of Bremerton, the considerably higher elevation of the city relative to NBK leaves the city largely safe from sea level rise and storm surge. As a consequence, Bremerton has not begun planning for climate change in the vicinity of the shipyard (Floyd 2015). The City and the base are closely linked via numerous infrastructure systems (see discussion in section 2.3), and collaboration on climate change adaptation planning will likely be necessary in the future. The analysis contained within this research project will examine the plans and policies of the White House, Department of Defense, Department of the Navy, NAVFAC Headquarters, and NAVFAC PWD Kitsap to produce a coherent picture of the state of climate change adaptation planning for Naval Base Kitsap – Bremerton.

1.5. Thesis Structure

Following the introductory Chapter 1, the literature review in Chapter 2 builds upon and expands the topics presented in the opening section. The complete research methodology is presented in Chapter 3. Chapters 4, 5, and 6 are devoted to case studies of adaptation planning at the Port of Rotterdam, Port of San Diego, and Naval Base Kitsap – Bremerton, respectively. Chapter 7 critiques the robustness of the adaptation choices made by the ports, and derives a practical climate change adaptation planning framework for U.S. Navy infrastructure planners. Chapter 8 discusses the findings, and Chapter 9 closes the research effort with final conclusions and suggested areas for future study.

2. Literature Review

2.1. Introduction

This literature review supports the analytical framework used to examine the ports studied. The review of the climate change literature is divided into sections based on the sub-questions of section 1.2:

- Climate Scenario Choices
- Decision Support Tool Choices
- Adaptation Strategy Choices
- Planned Adaptation Actions
- Chosen Adaptation Planning Timeframe
- Adaptation Financing Choices

2.2. Climate Change

2.2.1. Observed Climate Change

The most direct result of climate change is global warming: the increase in the average temperature worldwide over land and water. Over the period 1880-2012 average global temperature increased by more than 1.5° Fahrenheit (IPCC 2014, 5), and in the U.S. average temperature increased 1.3° to 1.9° Fahrenheit from 1895-2012 (Melillo, Richmond, and Yohe 2014, 12). Most of the increase has occurred since 1970, and the most recent decade was the warmest on record (Ibid.). The Polar Regions experienced the greatest amount of warming, leading to large-scale melting of Artic Sea ice (Melillo, Richmond, and Yohe 2014, 18).The increase in temperature is not an isolated phenomenon. Heat waves, cold waves, and droughts have also become more common (Melillo, Richmond, and Yohe 2014, 24-27; IPCC 2014, 20-23;

Herring *et al* 2014). Hurricane intensity in the North Atlantic is increasing, as is the frequency and destructive power of summer and winter storms (Melillo, Richmond, and Yohe 2014, 16). Changes in precipitation are also occurring across the U.S., with some areas experiencing greater seasonal variation in rainfall as well as an increase in rainfall intensity. Other areas are also experiencing more widespread and longer-lasting drought conditions. One of the largest changes, and potentially the most disruptive as far as coastal infrastructure is concerned, is sea level rise. Average sea level worldwide has risen 8" since 1880 (Melillo, Richmond, and Yohe 2014, 17; IPCC 2014, 11), though local variation in sea level rise occurs due to tidal variation, subsidence, glacial rebound, and other phenomena.

2.2.2. Future Climate Scenarios

Instigation of global climate change is largely attributed to greenhouse gases generated by human action (Melillo, Richmond, and Yohe 2014; IPCC 2014; Van den Hurk *et al* 2014; Herring *et al* 2014; Anderegg *et al* 2010). Although most governments generally agree on the need to substantially reduce GHG generation (United Nations 2014), reduction policies may not become truly effective for decades or even centuries (Melillo, Richmond, and Yohe 2014, 28-31). Scientists have extensively modeled expected climate conditions in an attempt to peer into the future (Pennel and Reichler (2011) counted at least 24 different models). Not unexpectedly, the models do not agree on future climate conditions due to widely differing assumptions made during model development (Ibid.).

A common approach in the empirical literature and public policy for mediating disagreements between climate models is to develop a range of future climate scenarios, such as those developed by Van den Hurk *et al* (2014) for The Netherlands (Nicholls *et al* 2013). Doing so provides common understanding and a ready-made discussion framework for policy development. A weakness in U.S. climate change adaptation policy is the diversity of climate scenarios predicting widely varying climate changes (Parris *et al* 2012), which in turn leads to political gridlock over the timing and extent of climate change expected (Kalra *et al* 2014).

This policy gap is particularly problematic with respect to projected sea level rise, where the potential damages from rising seas are incredible. Crowell *et al* (2010) estimated approximately 3% of the American population currently lives in 100-year coastal flood hazard areas. As sea levels rise, the population – and infrastructure – at risk will undoubtedly increase. As a regional example of the risk to coastal infrastructure, Kafalenos *et al* (2008) found 24% of interstate miles and 28% of secondary road miles in the U.S. Gulf Coast region are built at elevations of 4 feet or less, leaving them at risk of perpetual ocean inundation by 2100.

Absent official guidance regarding sea level rise projections, coastal infrastructure planning must proceed based on analysis of existing reports or specially commissioned expert opinions (Parris *et al* 2012). This ad hoc approach leaves considerable room for error and inefficiency as coastal planners work independently on adaptation planning. The National Oceanographic and Atmospheric Association (NOAA) attempted to bridge this gap in 2012 by publishing four global sea level rise scenarios for 2100 (see Table 2-1). The scenarios resulted from a review of the existing scientific literature and consultation with experts, and are bounded with high levels of confidence.

Table 2-1. Global sea level rise scenarios (Parris *et al* 2012)

Scenario	Sea level rise by 2100
Highest	6.6 ft (2.0 m)
Intermediate-High	3.9 ft (1.18 m)
Intermediate-Low	1.6 ft (0.9 m)
Lowest	0.7 ft (0.21 m)

Generally, scientists specifically avoid assigning probabilities to sea level rise since no method for predicting sea level rise probability is accepted over a multi-decadal scale (Parris *et al* 2012; SERDP 2013). In consequence, U.S. government agencies recommend using multiple scenarios (Dean *et al* 1987), such as those developed by NOAA, to bound the range of likely outcomes (e.g., Parris *et al* 2012; USACE 2013). None of the scenarios should be used alone, but in conjunction with the others to ensure adaptation plans are robust to a range of likely futures (Parris *et al* 2012; Burke *et al* 2008). However, the sea level rise scenarios in Table 2-1 are global in scope, and specific adaptation plans must be based on further analysis of sea level rise projections at the local and regional level (Parris *et al* 2012). SERDP (2013) concurred, noting that translating these global scenarios into actionable information still requires specific research to account for local conditions. This method can be characterized as "top-down" scenario development.

The United States Army Corps of Engineers (USACE) Directorate of Civil Works[16] has taken a different approach to scenario development by utilizing a "bottom-up" methodology for development of multiple scenarios (USACE 2014a). Beginning in 2011 USACE recommended

[16] The USACE Directorate of Civil Works manages large-scale, non-military infrastructure such as dams, levees, navigation works, and recreation (USACE 2015). Its policies do not apply to military installations managed by USACE.

its civil planners develop their own local and regional sea level rise scenarios based on extrapolation of observed tidal data (lowest sea level rise scenario), and derived equations from the National Resources Council (intermediate and highest scenarios). USACE (2014b) even developed an online calculator to assist its coastal planners in calculating the bounds of estimated sea level rise.[17] Deciding which scenario to use for a given purpose is still left to the discretion of local Civil Works authorities (USACE 2014b).

A third approach to scenario development is to leverage computing power to generate a very large ensemble (e.g., 100s or 1000s) of climate scenarios, rather than rely upon a small subset of scenarios. Known as "robust decision-making" (RDM), this approach is strongly endorsed by the World Bank and the RAND Corporation. Its proponents argue RDM is a superior approach to the traditional "Predict-then-Act" model of climate scenario development dominating the preceding discussion (e.g., Lempert and Schlesinger 2000; Hallegatte 2009; Bonzanigo and Kalra 2014; Kalra *et al* 2014). Rather than develop plans based on a small, predetermined set of climate scenarios for adaptation planning (i.e., low, medium, and high sea level rise projections), robust decision-making works backwards: develop climate adaptation plans first, then compare those plans against the scenarios with high impacts or consequences to evaluate the robustness of the proposed plans.

Doing so supports evaluation of the strengths and weaknesses of plans as well adjustment of the plans to improve robustness to a larger variety of climate scenarios than the limited number utilized in a traditional "Predict-then-Act" decision model (Kalra *et al* 2014). Among other

[17] http://www.corpsclimate.us/ccaceslcurves.cfm

benefits, RDM leads to plans which are adaptive to the many unknowns inherent to future climate change (e.g., effect of greenhouse gas reductions policies, rate of sea level rise, etc.) without making expensive capital improvements which may prove inadequate or even unnecessary for the level of climate change which actually occurs (Hallegatte 2009; Kalra *et al* 2014). RDM is discussed in further detail in section 2.4.2.

2.3. Effects of Climate Change on U.S. Navy Coastal Infrastructure

The effect of climate change on the U.S. Navy's coastal infrastructure will vary broadly based on the location of the infrastructure in question and local climate variables. Although some naval bases may be minimally affected by climate change, the overall viability of other bases may be called into question (Burke *et al* 2008; National Research Council 2011). One of the most obvious examples of climate change is sea level rise, the risk of which to coastal infrastructure is well-documented (Kong *et al* 2013; Field *et al* 2014; Melillo, Richmond, and Yohe 2014; Wilbanks and Fernandez 2012; Kafalenos *et al* 2008). In fact, Dr. Daniel Chu, Deputy Assistant Secretary of Defense for Strategy and Force Development, testified before the U.S. Congress in May 2014 that "Our coastal installations are already experiencing increased flooding and damage from sea-level rise and increased storm surge."

Not all agree on the paramount importance of sea level rise in infrastructure planning. The National Research Council (2011) relied upon the findings of Pugh (1996) and Flather *et al* (2001) to state that relative sea level rise is of secondary interest to the impact of severe weather-related events (i.e., storm surge), which will change based on sea level, tidal variation, and other climatic variables (National Research Council 2011). Others consider storm surge and sea level rise jointly as risks to infrastructure (Gill *et al* 2009). To further emphasize the point, the majority of damage to ports during Hurricane Sandy resulted from inundation which occurred when storm surge coincided with high tide (Wakeman 2013).

Work by Kong *et al* (2013) for Australia's National Climate Change Adaptation Research Facility considers the effects of sea level rise, storm surge, and other climate change effects on port infrastructure. Their work is paired with Wilbanks *et al* (2012) to produce Table 2-2.

Table 2-2. Effects of climate change on port infrastructure
(Adapted from Kong *et al* 2013; Wilbanks *et al* 2012)

Operational Environment	Port Asset	Climate Variable	Direct Impact on Infrastructure	Indirect Impact on Infrastructure
Landside	Berthing structures Protection barriers[18] Port superstructure[19]	- Severe weather frequency - Sea level rise - Ocean swell - Ocean acidification - Wet/dry spell variation - Temperature/heat wave - Extreme rainfall - Wind intensity	- Storm damage - Inundation and flooding - Tidal and splash zones shift - Wave overtopping of protection barriers - Barrier erosion and displacement - Degradation and failure of superstructure - Erosion / loss of coastal land - Increase in nonpoint source pollution	- Maintenance/ replacement costs increase - Electricity demand increases - Harbor exposure to ocean swells - Damage to goods/cargo - Shipping delays - Risk of liability for port damage
Seaside	Port channels Harbor basins Wetlands Barrier islands	- Wave action - Precipitation variation - Sea level rise - Storms - Storm surge	- Water depth and flow changes - Sedimentation (+/-) - Variation in seasonal high and low water - Erosion / loss of wetlands and barrier islands	- Bank failure - Increased loading on structures - Ship maneuverability - Regularity of ship traffic
Transport	Road infrastructure Rail infrastructure	- Temperature/heat wave - Solar radiation - Wet/dry spell variation - Precipitation variation - Sea level rise	- Inundation and flooding - Sub-base damage - Embrittlement / cracking - Potholing	- Maintenance/ replacement costs increase - Access restrictions - Interruption of port activity

[18] Breakwaters, seawalls, revetments, etc.
[19] All buildings, structures, and terminal facilities.

The table does not include all Navy functions and infrastructure at risk, i.e., wetlands, barrier islands, and other environmental areas; utilities, including generation, transport, and storage; and freshwater wells (National Research Council 2011).

The interdependency of infrastructure systems (see Table 2-3) must also be considered when evaluating the effect of climate change on infrastructure. Disruption of a critical infrastructure system (e.g.., electricity) by a climate event may lead to cascading failures in other systems and functions, such as water, transportation, and emergency response. (Kirshen, Ruth, and Anderson 2008; Wilbanks *et al* 2012). Cutter *et al* (2014) takes special note of the interrelated infrastructure failures experienced during Hurricanes Katrina and Sandy as clear examples of the interconnected vulnerabilities of infrastructure systems.

Table 2-3. Interdependence of infrastructure systems
(Adapted from Wilbanks *et al* 2012, 35)

Disrupted / Impacted	Electric Distribution	Natural Gas	Petroleum	Commun-ication	Water Distribution	Transport-ation	Public Health/ Sanitation
Electric Distribution	N/A	Medium	Strong	Strong	Strong	Weak	Strong
Natural Gas	Strong	N/A	Weak	Strong	Weak	Weak	Weak
Petroleum	Strong	Weak	N/A	Weak	Weak	Strong	Strong
Communication	Strong	Strong	Strong	N/A	Strong	Medium	Strong
Water Distribution	Strong	Weak	Weak	Strong	N/A	Weak	Strong
Transportation	Medium	Medium	Strong	Medium	Weak	N/A	Strong
Public Health/ Sanitation	Strong	Weak	Medium	Strong	Strong	Strong	N/A

Functional Interdependence	
	Weak
	Medium
	Strong

A final item of emphasis is the functional interdependency of different entities, such as governments, military bases, and utility providers (Becker *et al* 2014). The effects of climate change are not restricted to the installation's boundaries, but are regional in scope. If a military installation as a whole is prepared for climate change, but the organizations supporting the installation, such as utilities (water, sewer, electricity), city (streets), state (highways), etc., are not prepared, the military's operations may still experience substantial operational impact (Cutter *et al* 2014; CNA 2014). As a consequence, every effort should be made to coordinate climate change adaptation strategies at a regional level (NFESC 2009; 57).

2.4. Decision-Making for Climate Change Adaptation

2.4.1. Uncertainty and Climate Change

The effects of sea level rise, extreme weather events and other climate change-related phenomena have been intensively studied and debated. A key theme of the climate change literature is the uncertainty, or even "deep uncertainty,"[20] of climate change projections (e.g., Wardekker 2011; Bonzanigo and Kalra 2014; Gill *et al* 2009; Hallegatte 2009; Huizinga 2010; Kalra *et al* 2014). Numerous typologies for classifying uncertainty have been suggested (e.g., Thomson *et al* 2005; Hallegatte 2009), though one example is presented here from an oft-cited paper by Walker *et al* (2003).

[20] "Deep uncertainty" is used to describe a range of outcomes which are known, but the probabilities of the outcomes actually occurring are unknown, and will always remain so (Knight 1921; Hallegatte *et al* 2012). In the case of climate change, the potential risks of climate change are known (sea level rise, global warming, etc.), yet the probability of those changes occurring cannot be calculated. This concept, also referred to as "Knightian Uncertainty," is a twin to the concept of "Knightian Risk," which describes risks for which probabilities can be developed (Hallegatte *et al* 2012). Lempert and Schlesinger (2000) suggest "deep uncertainty" also describes a situation in which decision-makers do not understand or do not agree on the most appropriate model for predicting future climate change.

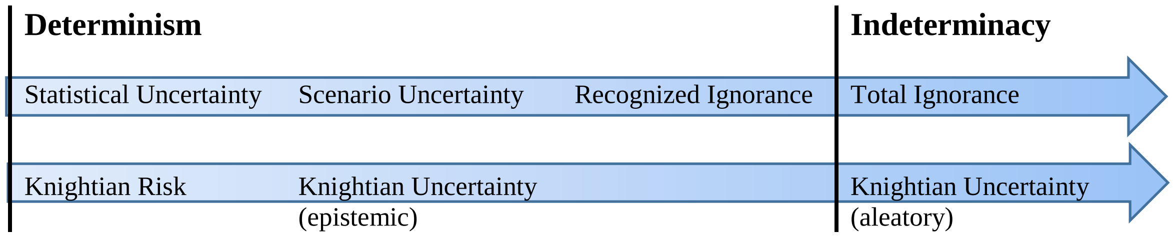
The uncertainty typology highlights three interrelated types of uncertainty with respect to complex models (such as those use for climate scenario development) (Ibid.):

- Level of uncertainty
- Location of uncertainty
- Nature of uncertainty

The first consideration is the *level of uncertainty* which influences development of the climate model. As shown in Figure 2.1, the span of uncertainty ranges from statistically uncertain to completely unknown. Statistical uncertainty, which coincides with "Knightian Risk," is well understood and can be described in probabilistic terms (Walker *et al* 2003; Knight 1921; Hallegatte 2009). Measurement and sampling errors are examples of this uncertainty. Scenario uncertainty refers to a group of potential changes, the general range of which is understood but the probability and timing are not. Climate scenarios are the embodiment of this uncertainty.

Recognized ignorance refers to climate changes which we are aware of, but do not understand and cannot model appropriately. Recognized ignorance can be further subdivided into reducible and irreducible ignorance, the first which is possible to reduce with further research, whereas the second, while acknowledged, cannot be adequately addressed. (Walker *et al* 2003). Total ignorance represents climate changes which are neither foreseen nor anticipated: "unknown unknowns," sometimes referred to as "wildcards" (Mendonça *et al* 2004) or "black swans" (Taleb 2007).

Figure 2.1. Transition from Determinism to Indeterminacy
(Adapted from Walker *et al* 2003, 12)



Locational uncertainty (first mentioned in section 2.2.2) can occur at a number of points within a climate change model (Walker *et al* 2003; Dessai and van der Sluijs 2007). Giorgi (2005) offers examples of different inputs which may affect development of a climate scenario, including socio-economic and GHG emissions assumptions, climate data utilized, and policy responses, and how those inputs combine to create uncertainty. Uncertainty may also occur within a climate model due to its technical construction and computer interpretation of the model (Walker *et al* 2003). This uncertainty extends to the down-scaling of global climate models, a necessary step for producing usable projections for local adaptation decision-making (Hallegatte 2009; Gay and Estrada 2010).

The final category is the *nature of uncertainty* within the climate model (Walker *et al* 2003). This uncertainty extends from "scenario uncertainty" to "total ignorance," and is coincident with the broader Knightian uncertainty description offered by Hallegatte *et al* (2012). Aleatory uncertainty and epistemic uncertainty comprise the two classes of Knightian uncertainty (Hallegatte *et al* 2012; Walker *et al* 2003), and have been depicted in their relative positions in Figure 2.2.

Aleatory uncertainty[21] ("total ignorance" in Figure 2.1) describes factors which cannot be predicted nor foreseen (Ayyub and Klir 2006). Even with greater human knowledge, this uncertainty cannot be reduced or eliminated due to its inherent randomness. Epistemic uncertainty, on the other hand, identifies factors which are beyond the current knowledge of mankind, but can be reduced with better data and information (Hallegate *et al* 2012; Ayyub and Klir 2006). This uncertainty is considered subjective, and as such is generally represented as a probability estimate in risk analyses.

2.4.2. Decision Support Tools for Climate Change Adaptation

Given the foregoing discussion of uncertainty, one would not fault a policy-maker for throwing their hands up in frustration at the fuzziness of it all. Yet key planning decisions must be made, even under uncertainty, given the long service life of most infrastructure (Hallegatte 2009). The traditional decision-support tools for infrastructure planning (see Figure 2.2) – cost-benefit analysis, cost-effectiveness analysis, and multi-criteria analysis – do not fare well under the uncertainties inherent to climate change projections (e.g., Hunt and Watkiss 2011; Hallegatte 2009; Dessai and van der Sluijs 2007). Consequently, it behooves decision-makers to utilize other tools which consider uncertainty when developing capital improvement plans.

A strong approach for considering uncertainty is robust decision-making (RDM) and its related variants, first discussed in section 2.2.2 (Kalra *et al* 2014; Hallegatte 2009). RDM is not the only alternative option for making adaptation decisions under uncertainty, however (see Figure 2.3).

[21] Also known as "ontic," "ontological," or "variability" uncertainty (Walker *et al* 2003). Former U.S. Secretary of Defense Donald Rumsfeld famously described aleatory uncertainty in military affairs as "unknown unknowns" (quoted in Ayyub and Klir 2006).

Figure 2.2. Summary of Traditional Decision Support Tools
(Adapted from Werners *et al* 2013, 10)

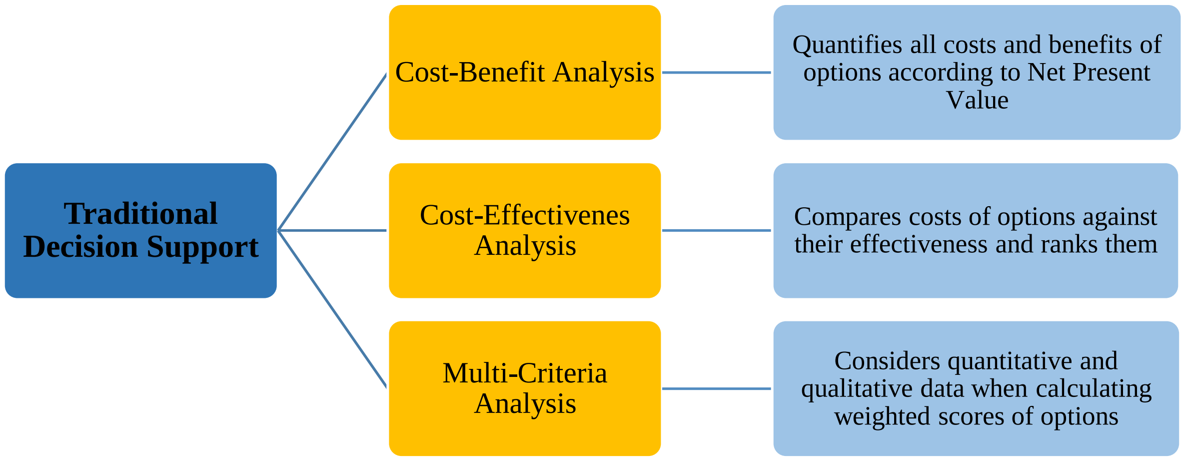
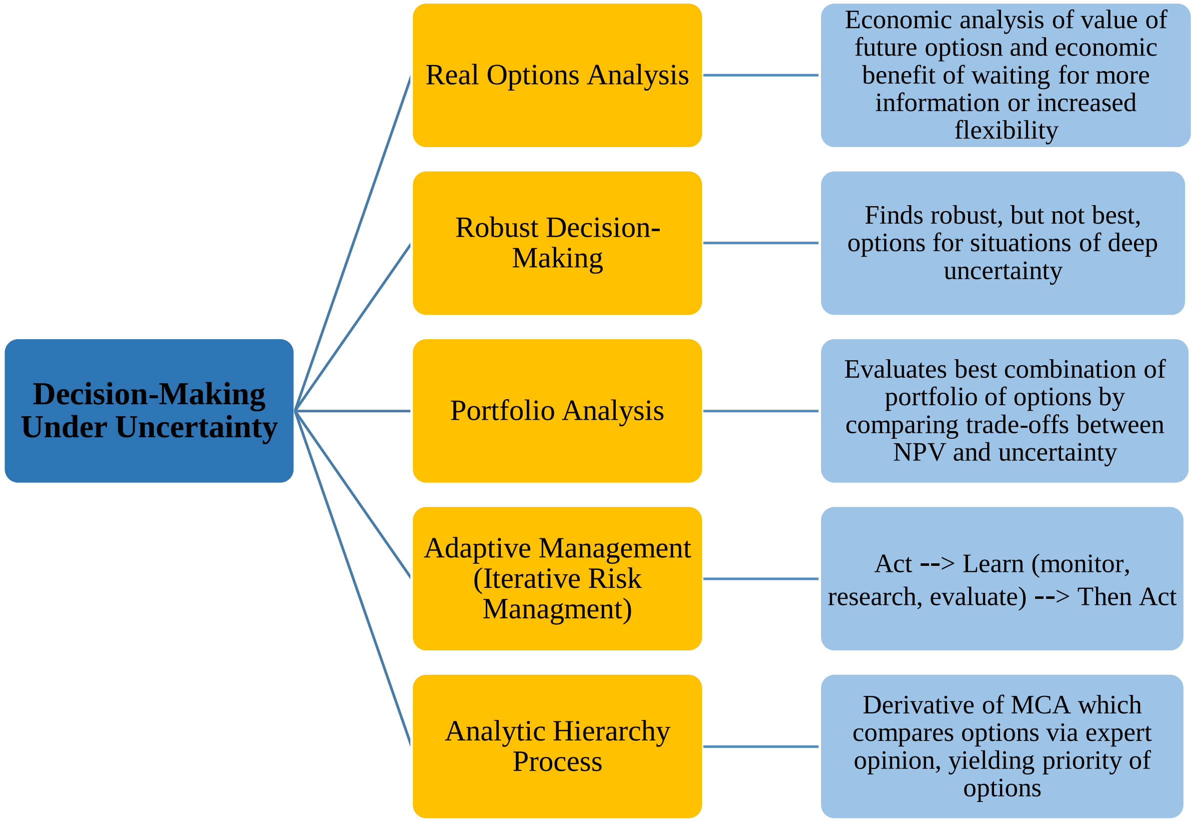


Figure 2.3. Summary of Non-Traditional Decision Support Tools
(Adapted from Werners *et al* 2013, 10)



Dessai and van der Sluijs (2007) analyzed several of the most common frameworks for decision-making under uncertainty and found that no decision-making framework was optimal under all conditions of uncertainty (see Table 2-4). Unique adaptation challenges merit unique adaptation objectives as well as selection of the most appropriate decision support tool (Werners *et al* 2013). Furthermore, using one decision-making tool does not preclude using another; combining frameworks to make adaptation decisions is a promising approach (Werners *et al* 2013; Hallegatte 2009; Hallegatte *et al* 2012; Whittington 2014).

Table 2-4. Evaluation of decision-making frameworks under uncertainty
(Dessai and van der Sluijs 2007, 60)

Frameworks for decision-making under uncertainty	Statistical Uncertainty	Scenario Uncertainty	Recognized Ignorance & Total Ignorance
IPCC Approach	+	++	--
Risk Approaches	++	+	--
Engineering Safety Margin	++	+/-	-
Anticipating Design	++	+	+
Resilience	+/-	+	++
Adaptive Management	++	-	--
Prevention Principle	++	+/-	--
Precautionary Principle	+	++	++
Human Development Approaches	+/-	+	+
Adaptation Policy Framework	+	+	+
Robust Decision-Making	+	++	+

Legend: ++ very good; + good; +/- somewhat; - bad; -- very bad

2.4.3. Making Robust Decisions

Robust decision-making (RDM) is a compelling alternative to the standard decision-making tools due to its ability to reach beyond small sets climate scenarios and consider scores of potential futures, more thoroughly testing the "robustness" of adaptation alternatives to climate change (Lempert, Popper and Bankes 2003). As shown in Table 2-4, RDM and the Precautionary Principle[22] perform well or very well under all levels of uncertainty. Furthermore, Whittington and Young (2014) emphasize that RDM assists officials with making decisions which are satisfactory (e.g., robust rather than optimal) over the long lifetimes of infrastructure systems. Sometimes this leads to decisions which are not the most cost-effective in the short term, but are more likely result in facilities resilient to the widest range of climatic conditions over the long lifetime of infrastructure systems (Whittington and Young 2014, 9). Resilient systems are those which "adapt, adjust, and change to internal and external stressors," whereas robust systems "function and perform with specifications regardless of external stressors" (USACE 2014a, 1-2). Coastal dunes and dams are examples of a resilient and robust systems, respectively.

RDM works by pushing for agreement on decisions, rather than agreement on assumptions (Kalra *et al* 2014). Attempting to agree on assumptions of future climate change frequently leads to disagreement and gridlock among stakeholders, stifling debate, and hindering effective action (Hallegatte 2009). In contrast, decision-makers should seek to "agree on decisions" by discussing potential adaptation measures, not divisive assumptions regarding the potential climate of the future. The questions which decision-makers should debate with regard to adaptation actions are (Kalra *et al* 2014, 15-16):

[22] The "precautionary principle," as defined by Gollier and Treich (2003), is bias toward premature investments in prevention of future harm. Such a decision-making philosophy values temporary, flexible investments made in the absence of sufficient scientific information, and seeks to avoid actions which unavoidably reduce future flexibility. Essentially, one is buying time to make a decision until better data is available (Randall, 177). In application RDM and the precautionary principle yield similar results (Lempert and Collins 2007; Hallegatte 2009), thus discussion in this paper is focused on RDM.

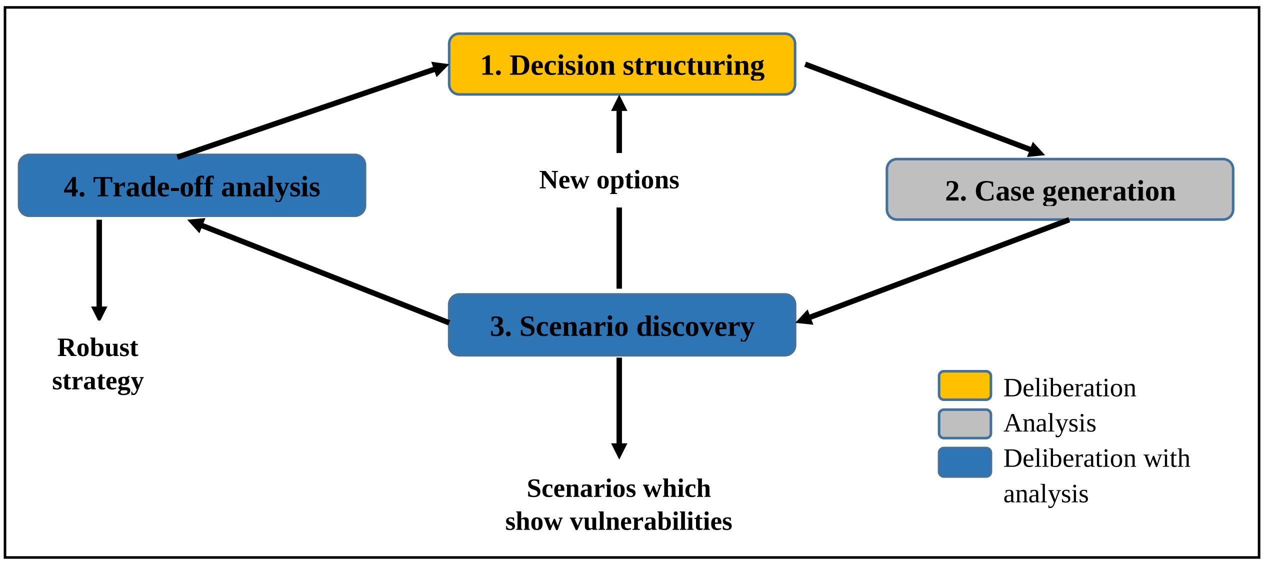
- How poorly must an adaptation measure perform before officials choose another adaptation measure which would perform better with the same likelihood of poor conditions?
- Which tradeoffs are officials willing to make between robustness and factors such as cost, environmental impact, etc.?
- Which adaptation options reserve the most flexibility with regard to future change?

By answering these questions, decision-makers will select adaptation measures which are "good" for a large variety of scenarios and stakeholder worldviews, but likely will not be "optimal" for any scenario or stakeholder (Kalra *et al* 2014, 14-16). The primary benefits of RDM are three-fold (Kalra *et al* 2014, 16):

1. Stakeholder consensus on adaptation actions, even among widely divergent viewpoints.
2. Identification of tradeoffs which must be made for adaptation measures.
3. Facilitation of policy which may mitigate the impact of adaptation actions on stakeholders

The four-step RDM process, as illustrated recently by Lempert *et al* (2013, 2), is shown in Figure 2.4. As explained by Kalra *et al* (2014, 22), step 1 of RDM requires decision-makers and analysts to develop objectives, uncertainties (e.g., climate variables, such as speed of sea level rise and extent of global warming), and adaptation plans for analysis. In the second step analysts leverage computer models to evaluate decisions under hundreds or thousands of different climate scenarios. The third step requires analysis of the modeling results to understand vulnerabilities of various decisions, i.e., under what conditions the chosen adaptation actions would not meet the chosen objectives. This process may suggest alternatives, which would re-direct the process to step 1, or trade-offs may be evaluated (step 4) between the "robustness" of the adaptation measures and other factors, such as cost. This process is continued until a robust strategy comprised of various adaptation actions is chosen.

Figure 2.4. Robust decision-making framework
(Adapted from Lempert *et al* 2013, 2)



Although RDM is a powerful tool with respect to development of climate change adaptation strategies and has been applied in practice (e.g., water management applications discussed by Lempert and Groves 2010), it is not an infallible process to be used in all circumstances. In its purest form RDM requires large amounts of quantitative information, computational power, and expert knowledge (Lempert and Groves 2010, 973; Werners *et al* 2013, 9; Hallegatte 2009). Such an approach may not be feasible for all governments or organizations operating under time, fiscal, and personnel constraints.

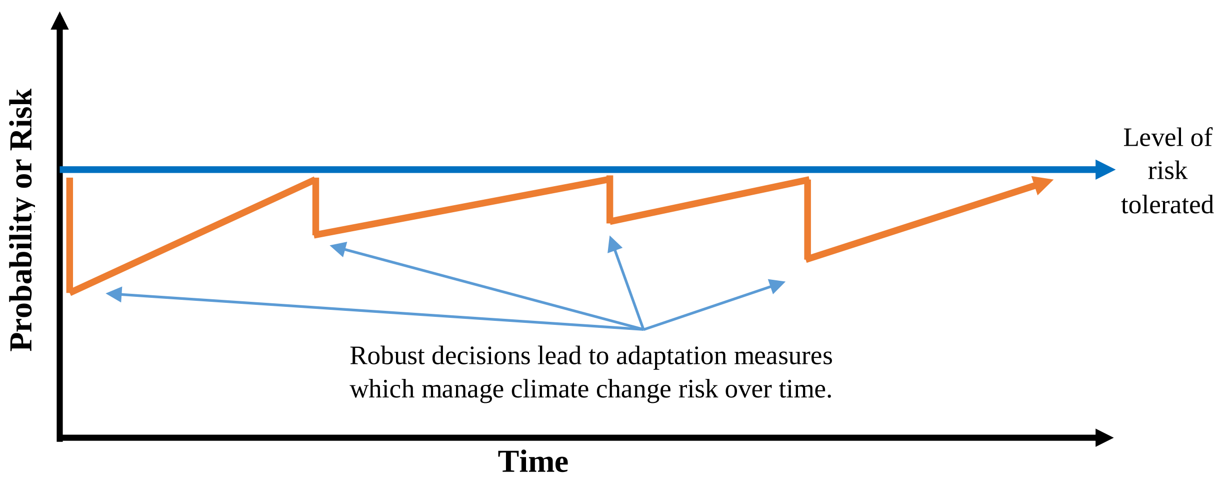
With these limitations in mind, Hallegatte (2009, 243-246) and Kalra *et al* (2014, 20-21) identified commonalities across RDM, the precautionary principle, and other related decision support tools as a starting point for choosing adaptation actions:

- *No-regret* and *low-regret actions* which provide benefits under any scenario, even those which do not involve climate change. Examples include energy efficiency renovations of existing buildings and increasing groundwater recharge.
- *Reversible/flexible actions* which allow flexibility to change adaptation measures when needed. A common example is preventing construction within an area expected to become a coastal floodplain as sea levels rise. If the rise does not occur, the rule can be easily changed and development allowed. The opposite is much more difficult.
- *Safety margin actions* which reduce vulnerability at no or relatively minimal additional cost. The actions are especially important to consider for engineered strategies which cannot be easily reversed or changed, such as construction of sea dikes in an urban area.
- *Soft actions* which allow for adaptation without infrastructure construction. Examples include land-use planning, disaster insurance, very long-term infrastructure planning horizons, and early warning systems for disasters.
- *Actions which reduce decision horizons* until more accurate information can be obtained. For example, constructing temporary buildings with shorter service lives within an area anticipated to within a future floodplain due to sea level rise.
- *Actions which synergize* (or conflict) with climate change mitigation, environmental policies, economic programs and social needs.

When evaluating adaptation measures using a RDM-type decision support tool, several benefits become apparent. First is the ability to choose adaptation measures with the most positive scores ("most robust"), or those involving the least amount of regret (Hallegatte 2009). Second, RDM still allows the utilization of familiar tools, such as cost-benefit analysis and multi-criteria analysis, to choose the most robust adaptation measures (Kalra *et al* 2014).

The net result of this practical method to making robust decisions is closer to the adaptive management process (Brown *et al* 2011)[23] than formal robust decision-making (see Figure 2.5). The adaptive management approach uses "sequential decisions and implementation *based on learning and new knowledge*" [italics original] (USACE 2014a, 3-12).

Figure 2.5. Adaptive management with robust decisions
(Adapted from USACE 2014a, 3-11)



[23] Adaptive management, also known as iterative risk management, is discussed in section 2.4.2.

2.5. Adaptation Strategies and Actions for Ports

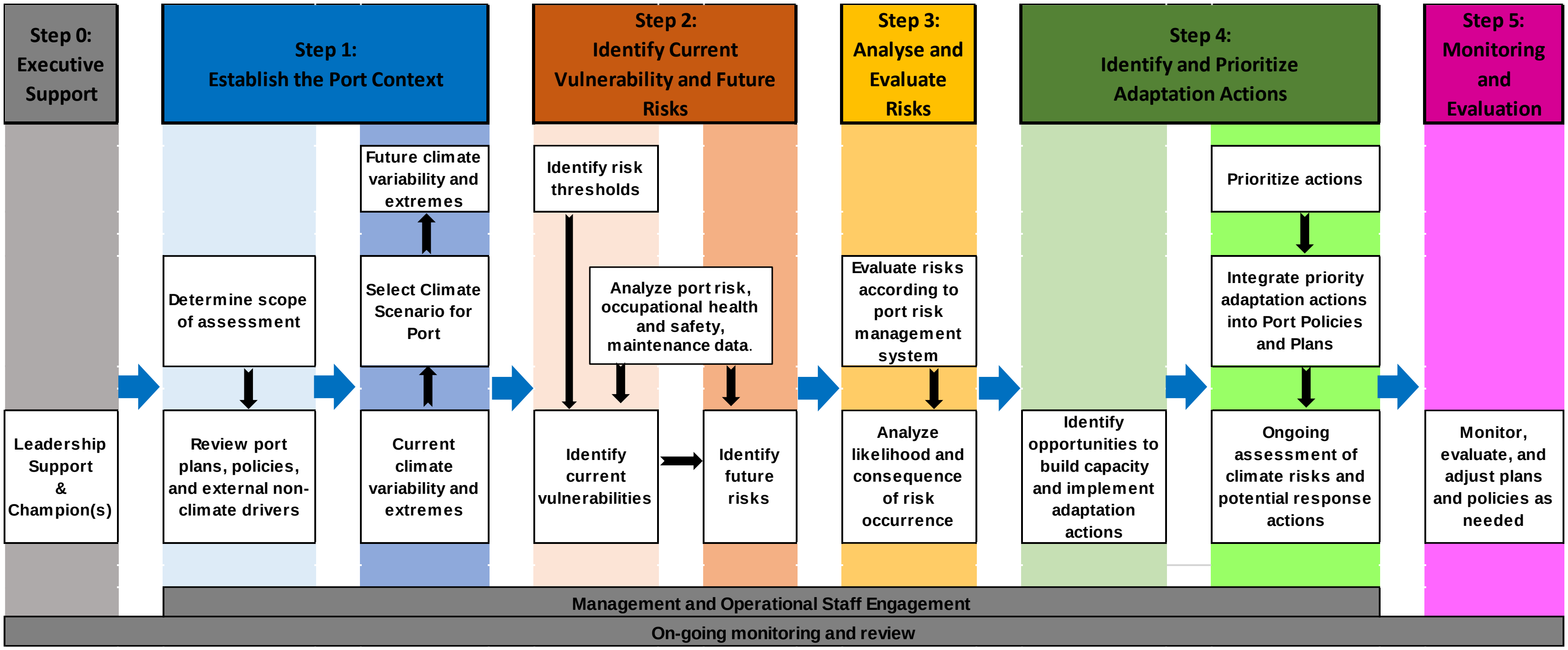
2.5.1. Adaptation Strategy Development Process

A number of step-by-step processes have been suggested for development of a climate change adaptation strategy (e.g., UKCIP 2014; Russell and Griggs 2012; NOAA 2010; USACE 2014a). In lieu of listing multiple methods, the straightforward process specified by Australia's *Climate Change Adaptation Guidelines for Ports* (Scott *et al* 2013, 7) is presented here for several reasons:

1. It is similar to the U.S. Navy's risk management process, "operational risk management."
2. It is based on the International Organization for Standardization (ISO) 31000:2009 "Risk Management Principles and Guidelines," a globally recognized management standard.
3. It focuses specifically on the port context.

The adaptation process steps for port infrastructure and adaptation to climate change are shown in Figure 2.6. Although this climate change adaptation methodology is recommended by Australia's *Climate Change Adaptation Guidelines for Ports* for legitimate reasons – audience familiarity, simplicity, etc. – it is not without weaknesses, particularly with regard to the uncertainty of future climate projections. Scott *et al* (2013) attempt to mitigate the uncertainty by recommending vulnerability analyses be jointly based on historical climate data and trends as well as future climate scenarios. Whether this hybrid version of adaptive management will be successful cannot be determined from the literature.

Figure 2.6. Hybrid Vulnerability / Risk Assessment Process for Ports
(Adapted from Scott *et al* 2013, 7)



2.5.2. Adaptation Strategy: Protect, Accommodate, or Withdraw

Although the general adaptation strategies are protect, accommodate, or retreat (Bijlsma *et al* 1996),[24] Becker *et al* (2013) provide a port-specific focus: "fortify storm defenses, elevate to compensate for projected sea levels, or relocate entirely." Logically, one may also add the neutral response options of "do nothing" and "rebuild-and-recover" to the list of available adaptation strategies.

Fortification of ports and port functions protects against climate change-related damage may be done only at great expense and to the detriment of the local environment (Becker *et al* 2013). Accommodation of climate change through adaptive development is a potential solution, but if the infrastructure systems which support the port (e.g., water, electricity, transportation, etc.) are impacted by climate change the port may still be rendered inoperable (Becker *et al* 2013; Cutter *et al* 2014). Furthermore, ports are already intensively developed, and large-scale accommodation measures would be difficult and expensive to implement. Finally, withdrawal or relocation by a military or commercial port is very difficult due to the physically constrained location of many ports, the lack of viable deep-water alternatives, and the very high cost of constructing a new port with the necessary supporting infrastructure (Becker *et al* 2013).

2.5.3. Adaptation Actions

The United Kingdom Climate Impacts Programme (UKCIP) classifies fortification, accommodation, or withdrawal actions as 1) those which provide opportunities to build adaptive capacity ("soft actions") and 2) those which build adaptive capacity ("hard actions") (Scott *et al*

[24] In the American military context "retreat" is an ill-favored word. "Withdraw" is the preferred substitute, and will be used subsequently.

2013). Table 2-5 illustrates how protect, accommodate, or withdraw adaptation actions for ports may be classified further based on their particular characteristics (Scott *et al* 2013; Hallegatte 2009; Kalra *et al* 2014):

- No Regrets/Low Regrets: actions which provides benefits in excess of costs, regardless of the level of climate change which actually occurs.
- Adaptation Synergy: actions which improve resilience while also providing additional climate change mitigation, environmental policies, economic programs, or social needs.
- Safety Margin: engineering actions which reduce vulnerability at no or relatively minimal additional cost.
- Reduce Decision Horizons: actions which allow delay on a much larger decision until more accurate information can be obtained, allowing for a more informed decision.
- Flexible/Adaptive Management: incremental adaptation measures which are not implemented until deemed necessary by contemporary needs, best-available science, and contemporary decision-makers.
- One-off Adaptation: single action which protects against projected levels of climate change for a specified time period. Generally applies only to “hard” adaptation choices, such as seawall construction.

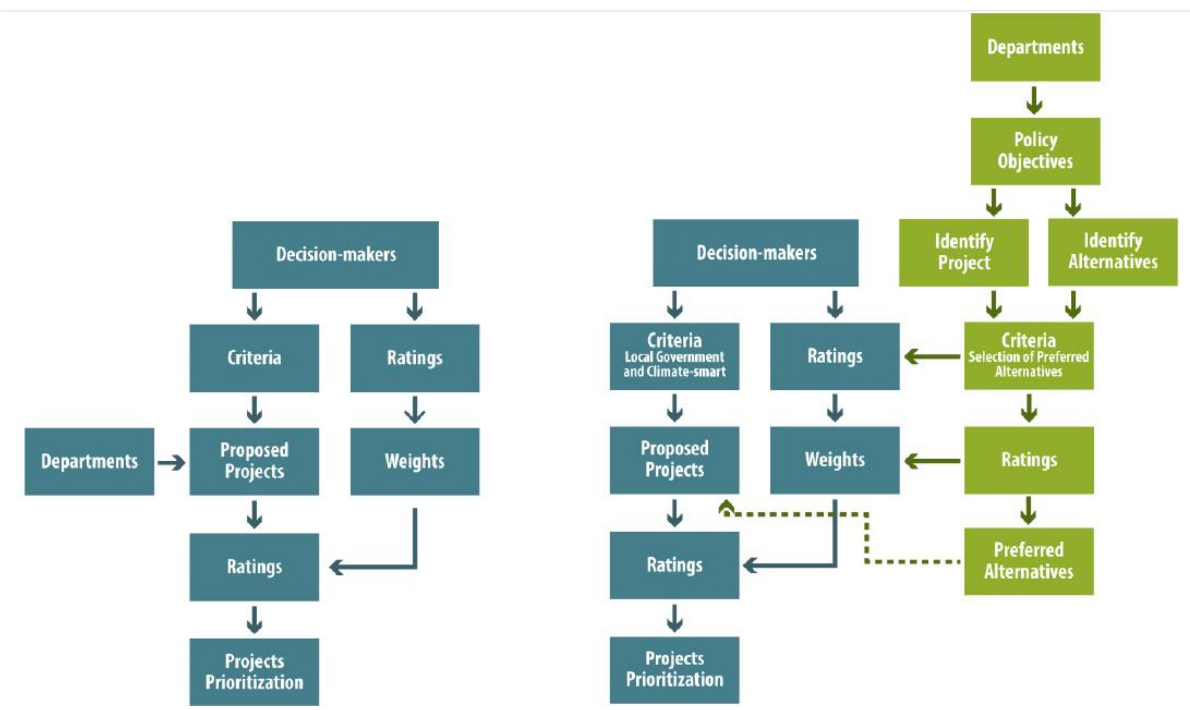
Table 2-5. Examples of Protect, Accommodate, and Withdraw adaptation options
(Adapted from Becker *et al* 2013; Klein *et al* 2000; NFESC 2009;
Hallegatte 2009; Kalra *et al* 2014; classification by author)

Strategy	Action	No/Low Regrets	Synergy	Safety Margin	Reduce Horizon	Flexible/ Adaptive	One-off
Protect							
Hard	Dikes, levees, floodwalls			X			X
	Seawalls, revetments, bulkheads			X			X
	Increase breakwater dimensions			X			X
Soft	Climate change vulnerability and risk assessment	X			X		
	Adaptation Plan	X			X	X	
	Beach nourishment		X		X	X	
	Dune creation / restoration		X		X	X	
	Wetland restoration / creation		X		X		
Accommodate							
Hard	Raise overall port elevation						X
	Raise transport infrastructure			X			X
	Increase dredging					X	
	Land use: i.e., convert low-lying land to natural area or parkland	X	X				
	Adapt pier design (i.e., floating piers)			X		X	X
	Improve drainage			X			X
Soft	Form climate change adaptation team	X				X	
	Improve resiliency of critical infrastructure (i.e., electrical)		X		X	X	
	Improve facility energy efficiency	X	X				
	Building codes: i.e., raise minimum elevation of new and renovated buildings and structures, increase building design loads – wind, snow, etc.)					X	
	Regulation of hazard zones				X		
	Emergency Planning: early warning system and evacuation plans	X			X		
	Increase water recycling	X	X		X	X	
Withdraw							
Hard	Relocate threatened buildings and functions.		X			X	X
Soft	Increase/establish set-back zones. Phase out development in susceptible areas.				X	X	
	Create upland buffers		X		X	X	

2.5.4. Incorporating Adaptation into Capital Improvement Programs

No single methodology is universally accepted for incorporation of adaptation planning into capital improvement planning. As a reasonable alternative Hallegatte (2009) and Kalra *et al* (2014) suggest incorporating adaptation into a typical multi-criteria analysis used to as part of capital improvement planning process. Whittington (2014) is developing a promising methodology, "Climate-Smart Capital Investment Planning," for the World Bank which allows consideration of GHG emissions during the capital improvement planning process. Although the process is not designed for evaluating adaptation measures *per se*, this adjustment could be easily made to incorporate the robustness characteristics listed in section 2.4.3 into the framework shown on the right side of Figure 2.7.

Figure 2.7. Traditional and Climate-Smart uses of multi-criteria analyses
(Whittington 2014)



2.5.5. Adaptation Planning Timeframe

When adaptation measures must be implemented depends greatly on the climate change risks to a specific location as well as the infrastructure or planning area concerned. Hallegatte (2009, 241) estimated the lifecycle and exposure of infrastructure systems and planning sectors to climate change (see Table 2-6). Although commercial ports generally consider themselves safe from climate change at the moment (Becker *et al* 2011; Becker *et al* 2014), such a position is short-sighted when the potential damage from climate change over the complete facility lifecycle is considered. Meyer (2008, 23) recommends focusing on infrastructure whose service life is more than 40-50 years (buildings, bridges, etc.) for more conservative adaptation design. Infrastructure with a shorter service life can be easily adapted at the next scheduled replacement when more information is available.

Conversely, Whittington and Young (2014, 9) argue that when considering infrastructure system resilience and climate change, there is no point in using short time-scales for infrastructure decisions. Doing so may seem economically efficient when the infrastructure decision is made, but wasteful over the long term if the structure is damaged or destroyed by an extreme event resulting from climate change. The long view is supported by the U.S. Army Corps of Engineers, which recommend use of a 100-year "adaptation horizon" for long service life projects to more effectively evaluate the resiliency of alternatives to potential climate changes (USACE 2014a, 1-3).

Table 2-6 Sectors which must consider climate change
(Hallegatte 2009, 241)

Sector	Time Scale (years)	Climate Change Exposure
Water infrastructure (e.g., dams, reservoirs)	30-200	+++
Land-use planning (e.g., in flood plain for coastal areas)	>100	+++
Coastline and flood defences (e.g., dikes, seawalls)	>50	+++
Building and housing (e.g., insulation, windows)	30-150	++
Transportation infrastructure (e.g., port, bridges)	30-200	+
Urbanism, (e.g., urban density, parks)	>100	+
Energy production (e.g., nuclear plant cooling system)	20-70	+

Legend: +++ High; ++ Medium; + Low

Although climate change in general is a concern, the effects of sea level rise, storm surge, and related problems clearly present the greatest threat to port operations and infrastructure (Gallivan, Bailey, and O'Rourke 2009; Kong *et al* 2013; Wilbanks *et al* 2012). As yet global sea level rise has been relatively modest at 8 inches since 1870 (Melillo, Richmond, and Yohe 2014, 17), and the short-term risks to port infrastructure can be clearly modeled. Yet the possibility of abrupt change resulting in six feet or more of sea level rise by 2100 cannot be discounted (Cazenave and Cozannet 2014). The likelihood and timing of this change is unknown (Ibid.; Melillo, Richmond, and Yohe 2014, 28), making it difficult for military and commercial ports to plan effectively. As noted in section 2.4.3, Hallegatte (2009) and Kalra *et al* (2014) recognized this dilemma and recommended the implementation over time of adaptation actions which possess the most robust characteristics or involve the least amount of regret.

Alternatively, military or commercial ports may choose to adapt conservatively now and prepare for the worst case sea level rise scenario. Such an approach may not be economically efficient if the extent or speed of sea level rise does not justify such approach for decades, if ever. A RDM study conducted for the Port of Los Angeles found the port did not need to harden facilities prior to the next scheduled upgrade despite the uncertainties surrounding future climate change (Lempert, Sriver, and Keller 2012; 30). The RDM analysis also predicted that one of the four facilities (a bridge) would likely require substantial improvement at the next scheduled upgrade, whereas the costs of upgrading the other three port facilities examined would need to be 5, 25, and 250 times lower, respectively, to make such improvements economically advisable (Ibid.).

2.5.6. Funding for Adaptation

Financing at the organizational level for climate change adaptation can be provided in a number of ways. First, adaptation may be a specific line item in a budget, though Becker *et al* (2011) found this is not a common occurrence at commercial ports. This has not occurred for the U.S. Navy, either. A second option is to incorporate adaption into all aspects of operations ("mainstreaming") such that adaptation becomes second-nature and does not require a specific funding process (Bouwer and Aerts 2006, 59). This would allow adaptation projects to vie with all other projects for funding via the traditional capital improvement planning process. Based on the author's conversations with Navy stakeholders, this appears to be the choice NAVFAC will adopt for adaptation financing. A third option for commercial ports is to pursue funding from an outside source, such as a government grant, commercial loan (Bouwer and Aerts 2006), or public-private partnership (Fankhouser and Agrawala 2006). A final option is to purchase insurance to fund rebuilding after climate affects are felt (Ibid.), though this would represent a break from the U.S. government's policy of self-insurance against accidents and damage to government property (US GAO 2005, 1).

3. Methodology

This chapter describes in detail the methodology used to investigate the research question and sub-questions introduced in section 1.5. The answers to the research question and sub-questions for each of the case studies, the crux of this project, are presented in a chart in Chapter 7. The chart highlights the six main choices made – or not made, as the case may be – by elected officials, government staff, and port authorities planning to adapt to climate change. By studying these adaptation choices, and how the choices were made, a framework for climate change adaptation planning for Navy infrastructure may be derived.

3.1. Research Question

The main research question which this project seeks to answer is, **"**How can the U.S. Navy most effectively plan to adapt its coastal infrastructure to climate change?" To answer the main question, the following sub-questions (with supporting exploratory questions) must be satisfactorily investigated via a rigorous document review and consultation with planners and stakeholders:

1. Which climate change scenario(s) did the port choose to rely upon to make adaptation decisions?
    a. Which climate change scenarios were reviewed?
    b. Which scenario was used for decision-making?
    c. Which infrastructure is at risk from climate change?
2. Which decision-support tools did the port choose to make adaptation decisions?
    a. Which entity is responsible for adaptation decision-making?
    b. Which decision support tool did the entity choose?

c. Why was that tool chosen?
d. How robust is the decision support tool?
e. How does the port address uncertainty in decision-making?

3. Which adaptation strategy did the port choose?
   a. Which policies (national, regional, local) affect climate change adaptation planning for the port?
   b. What was the process followed to develop the strategy?
   c. What are the foundational elements of the plan?
   d. Why were those elements chosen?
   e. How were stakeholders (agencies/institutions/governments) engaged regarding the strategy?
4. Which adaptation actions did the port choose?
   a. What are the adaptation priorities?
   b. How are adaptation priorities incorporated in the port's capital improvement program (CIP)?
   c. Which adaptation actions did the port choose?
   d. When will these adaptation actions be completed?
   e. Why were those actions chosen?
   f. How have these actions been incorporated into the CIP?
   g. Which adaptation actions have already been implemented?
5. Which funding source(s) did the port choose to finance implementation of their adaptation plans?
   a. Which funding sources are available to implement the adaptation plan?

    b. Which funding source(s) did the port choose?
    c. Why was that funding source chosen?

6. Which timeframe did the port choose for adaptation planning?
    a. What is the adaptation planning timeframe?
    b. Why was that timeframe chosen?
    c. When will the adaptation plan be re-evaluated?

3.2. Method of Investigation

All publicly available plans, policies, and documents regarding climate change adaptation planning at the three ports were reviewed for information and insight. From the documents key individuals involved in adaptation planning were identified and contacted for follow-up discussions to clarify various points which were not clear from the documents or the literature. The author's notes from each in-person or phone discussion were emailed back to the planners concerned for corrections and comments. Any feedback from the planners was incorporated into the overall thesis.

3.2.1. Port of Rotterdam Investigation

A document review and semi-structured interviews with stakeholders via phone and email formed the basis of research regarding adaptation planning for the Port of Port of Rotterdam. Table 3-1 lists the individuals consulted in December 2014.

Table 3-1. Individuals consulted regarding adaptation planning for the Port of Rotterdam

Name	Organization	Title
Nick van Barneveld	Municipality of Rotterdam	Senior Policy Advisor for Public Works / City Management / Water Department
Bart Kuipers, Ph.D.	Erasmus University Rotterdam	Senior Research Manager Port Economics
Marc Eisma	Port of Rotterdam Authority	Project Manager, Environmental Management
Robert Tieman	Deltalinqs	Environmental Policy Advisor
Hans van 't Noordende	Deltalinqs	Innovation Coordinator

3.2.2. Port of San Diego Investigation

A document review and semi-structured interviews with stakeholders via phone and email formed the basis of research regarding adaptation planning for the Port of San Diego. Table 3-2 lists the individuals consulted in January and February 2015.

Table 3-2. Individuals consulted regarding adaptation planning for the Port of San Diego

Name	Organization	Title
Raymond Pe	City of National City	Principal Planner
Clifford Maurer	City of Coronado	Director of Public Services and Engineering
Jim Nakagawa	City of Imperial Beach	City Planner, Community Development Department
Cody Hooven	Port of San Diego	Senior Environmental Specialist
Ed Batchelder	City of Chula Vista	Deputy Director, Development Services Department
Steve Power	City of Chula Vista	Principal Planner, Development Services Department

3.2.3. Naval Base Kitsap – Bremerton Investigation

A document review and semi-structured interviews with stakeholders via phone and email formed the basis of research regarding adaptation planning for Naval Base Kitsap – Bremerton. Table 3-3 lists the individuals consulted in January and February 2015.

Table 3-3. Individuals consulted regarding adaptation planning For Naval Base Kitsap – Bremerton

Name	Organization	Title
Rear Admiral Kevin Slates	U.S. Navy Chief of Naval Operations Staff	Director, Chief Of Naval Operations Energy and Environmental Readiness Division (OPNAV N45)
Commander John Marburger	U.S. Navy Task Force Climate Change	Climate Change Affairs Officer, Task Force Climate Change Office of the Oceanographer of the Navy (N2/N6E)
Lieutenant Commander Bob Stiles	Naval Mobile Construction Battalion ONE	Executive Officer (Former Assistant Public Works Officer for NBK)
Lieutenant Commander Brent Uyehara	NAVFAC PWD Kitsap	Assistant Public Works Officer
Steven Letson	NAVFAC PWD Kitsap	Waterfront Planner
Lieutenant Commander Jason Gabbard	U.S. Navy N4	N464C1
Katherine Touzinsky	USACE Engineering Research and Development Center	Knauss Marine Policy Fellow: Navigation R&D Advisor
Herb Collier Christopher Goalby	PSNS and IMF	Facilities Planning Staff
Susan Walker	NAVFAC Headquarters	Land Use Planner Sustainability & Land Use Planning Asset Management (AM3)
William Venable	NAVFAC Engineering and Expeditionary Warfare Center	Operations Department OP53
Nancy Ruiz	NAVFAC Engineering and Expeditionary Warfare Center	Environmental Department EV31
Nicole Floyd	City of Bremerton	Senior Land Use Planner

3.3. Analysis of Results

Relative to the Port of San Diego and Port of Rotterdam, it is fair to say Naval Base Kitsap – Bremerton (NBK) is not actively planning to adapt to climate change. Consequently, the outcome of this research effort will be an adaptation planning framework, informed by the literature and validated by analysis of adaptation choices made for the Port of Rotterdam and the Port of San Diego, for planners to use at U.S. Navy ports.

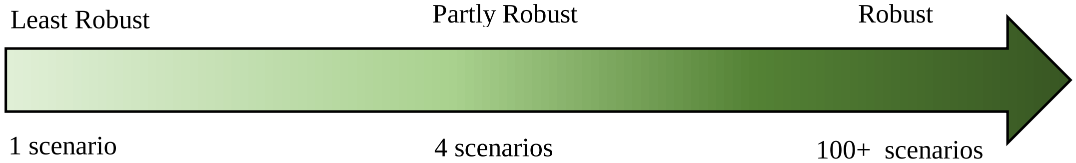
The adaptation planning framework will be based on the six key adaptation choices made by officials for the Port of Rotterdam and Port of San Diego. The ports' choices will be summarized in a chart to highlight differences and similarities between them as their adaptation planning progresses. To the extent possible, parallels will be drawn between the theoretical literature and the empirical development of climate change adaptation plans and policies. Each of the key choices made for the ports will be examined for robustness and consideration of uncertainty.

Of course, evaluating robustness in this manner requires subjectivity on the author's part which cannot be avoided. However, the author intends to explain his reasoning as fully as possible to allow readers to make their own determinations. For example, when conflicting choices are made for an adaptation choice, the author will determine the combined robustness of the overlapping decisions. As a case in point, divergent planning timeframes for the Port of Rotterdam are specified by the Port of Rotterdam Authority and the City of Rotterdam. The City of Rotterdam specifies minimum elevations of building ground floors, making the City's planning timeframe of the year 2100 (and the level of sea level rise expected at that time) more influential than the Port of Rotterdam Authority's stated preference of planning for 2050.

3.3.1. Robustness of Chosen Climate Scenario

As introduced in section 2.2.2, robust decisions cannot be made based on single scenario, but instead result from consideration of many scenarios, all of which are equally likely to occur (Lempert and Schlesinger 2000; Hallegatte 2009; Bonzanigo and Kalra 2014; Kalra *et al* 2014). As a result, for evaluation of this adaptation choice the level of robustness is determined by the number of scenarios used during development of the adaptation strategy (see Figure 3.1).

Figure 3.1. Robustness of climate scenario choice



3.3.2. Robustness of Chosen Decision-Support Tool

The mechanism for evaluating the robustness of a decision-support tool is provided by Dessai and van der Sluijs (2007, 60) (see section 2.4.2, Table 2-4). Although no decision support tool is best under all conditions of uncertainty (Ibid.), the ability of a tool to satisfactorily address multiple levels of uncertainty is a measure of its robustness. Organizations can improve the overall robustness of their adaptation planning by using multiple decision-support tools with strengths in different areas, which, when used collectively, result in more robust decisions (Hallegatte 2009; Werners *et al* 2013; Whittington 2014).

Table 3-4. Evaluation of robustness of decision support tools
(Adapted from Dessai and van der Sluijs 2007, 60)

Frameworks for decision-making under uncertainty	Statistical Uncertainty	Scenario Uncertainty	Recognized Ignorance & Total Ignorance
Decision support tool 1 (example)	-	+	++
Decision support tool 2 (example)	++	+	+/-

Legend: ++ very good; + good; +/- neutral; - bad; -- very bad

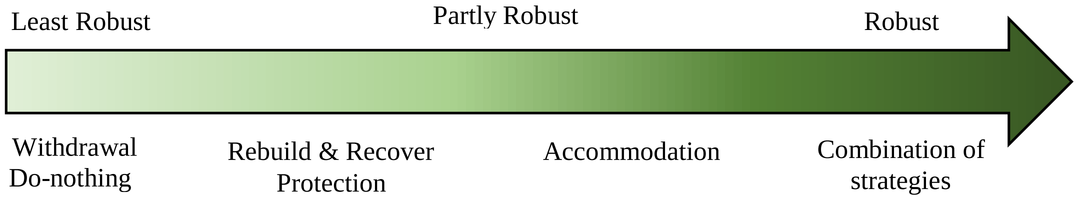
3.3.3. Robustness of Chosen Adaptation Strategy

Evaluating an adaptation strategy choice for robustness appears simple in theory. In practice, it is complicated since many port adaptation strategies are a combination of protection, accommodation, or withdrawal (Becker *et al* 2013), rather than a uniform approach (e.g., such as protecting the port with fortification)s. Evens so, it is possible to derive a rubric for evaluating robustness of a port adaptation strategies by process of deduction (see Figure 3.2).

As discussed in section 2.5.2, withdrawal is usually not a robust option for ports due to their physically constrained locations and lack of reasonable alternatives (Becker *et al* 2013). Instead ports will likely consider only protective or accommodative strategies. In a relative robustness comparison, accommodation will likely fare much better given the uncertainties of future climate change, whereas protection implies a massive fixed investment in infrastructure based on a specific set of assumptions. Furthermore, protection-based strategies frequently come at a high cost to the environment and to the investor's finances (Becker *et al* 2013). By this logic, a strategy of accommodation is at least somewhat robust, withdrawal least robust, and protection floats in the middle (see Figure 3.2). Doing nothing is also a possibility, though not a robust one given the risk of climate change. Rebuild and recover, a form of accommodation, is not as robust as anticipating and proactively preparing, though it may be the only reasonable approach for existing large-scale infrastructure systems.

As noted above no one strategy is most robust by itself, though accommodation comes the closest to that standard. Furthermore, port infrastructure is large, expensive, and fixed, limiting a port's ability rely solely upon accommodation as a strategy. A combination of strategies, though, is a promising approach for achieving the most robust results.

Figure 3.2. Robustness of port adaptation strategy



3.3.4. Robustness of Chosen Adaptation Actions

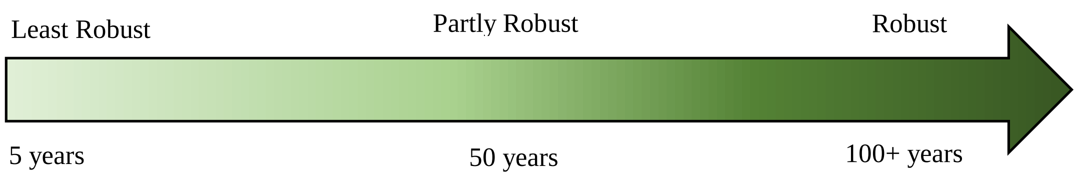
Due to the uncertainty associated with climate change, it is unlikely a single adaptation action will be sufficient to prepare a port for climate change. It is probable a bevy of measures must be chosen to improve the robustness of a port to climate change. For this analysis, if an adaptation action possesses at least one characteristic of robustness, it is judged at least partly robust. It follows, then, as the quantity of robust qualities increases, so does the robustness of the chosen adaptation measure. First discussed in section 2.4.3, the criteria for measuring the robustness of each adaptation action are adapted from Hallegatte (2009):

- No-regret or low-regret
- Synergizes with other priorities
- Provides a cheap safety margin
- Reduces decision horizons
- Easily reversible/flexible
- Soft

3.3.5. Robustness of Chosen Adaptation Planning Timeframe

As noted in section 2.5.5, using a longer adaptation planning timeframe or planning horizon leads to more robust choices (Whittington and Young 2014; USACE 2014a). As the planning horizon increases, so does the range of possible future climates, thus planners must choose adaptation options which perform satisfactorily under increasing uncertainty. For this study, then, robustness in planning timeframes will be based on length of the planning horizon (see Figure 3.3).

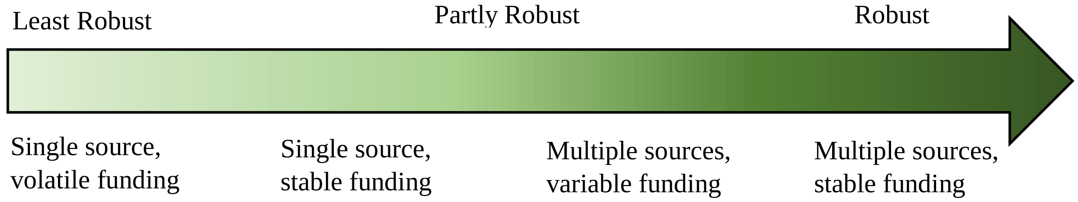
Figure 3.3. Robustness of planning timeframe choice



3.3.6. Robustness of Chosen Adaptation Financing Method

Robustness of adaptation financing cannot be directly evaluated in the same manner as adaptation measures or decision support tools. In this study, robust financing choices can be measured by the variety and stability of the chosen funding mechanisms, a number of which are suggested in section 2.5.6. A single financing mechanism which provides relatively volatile funding, such as sales tax, is not an adequately stable financing mechanism for a capital improvement program (Marlowe, Rivenbark, and Vogt 2009). A CIP financing mechanism based on a more stable source, such as property taxes, is better yet, and financing from multiple stable funding sources is the most robust of all (see Figure 3.4) (Ibid.).

Figure 3.4. Robustness of adaptation financing choice



3.4. Research Assumptions

This research project assumes U.S. Navy coastal infrastructure is already threatened by climate change, and that the Navy cannot wait to develop adaptation policy until more accurate information about the future climate is available. Regardless of the rate at which climate has occurred, is occurring, or will occur in the future, the U.S. Navy must plan to adjust to varying climate regimes, or risk being overtaken by events, such as loss or damage of key infrastructure and functions, which prevent accomplishment of the U.S. Navy's larger mission of ensuring the freedom of the seas.

Secondly, this research project assumes studying the adaptation planning of commercial ports in the U.S. and The Netherlands is a valid comparison to the adaptation planning of U.S. Navy coastal infrastructure. Commercial port authorities face the same climate change risks as U.S. Navy infrastructure planners, yet presumably are less encumbered by bureaucratic inertia and political freight, and thus are more agile in their decision-making. This political nimbleness allows port authorities to recognize and respond to climate change more quickly than the U.S. Navy. The Navy benefits, of course, from learning from the successes and failures of the trailblazing port authorities with regards to planning for climate change adaptation.

4. Adaptation Planning for the Port of Rotterdam

4.1. Introduction

Planning for adaptation to climate change for the Port of Rotterdam is not a straightforward process. Presumably, the long history of The Netherlands and water would lead to an anxiousness by the Port of Rotterdam Authority to face the challenge of climate change head-on. This research project found this presumption only partially true; the City of Rotterdam and the Dutch national government are actively planning for climate change, but the Port of Rotterdam Authority is not.

As noted in section 1.7.1, the Port of Rotterdam Authority is a limited public corporation jointly owned by the City of Rotterdam and the Dutch National Government, but managed by quasi-independent Supervisory and Executive Boards (Port of Rotterdam 2014b). This arrangement has ensnarled climate change adaptation planning for the Port of Rotterdam into a confusing tangle of plans, non-plans, and good intentions.

In 2012 the City of Rotterdam published the *Rotterdam Climate Change Adaptation Strategy*, which applies to the port since it sits upon city-owned land. Also influencing adaptation planning for the port is the “Delta Program,” which describes the macro-scale measures which the Dutch government will take to protect the country from the negative effects of climate change. On the other hand, the Port of Rotterdam Authority, does not yet have its own plan for adapting to climate change despite recognizing the threat of climate change (Eisma 2014).

Given the Port Authority of Rotterdam is not yet planning for climate change adaptation, this chapter explains the current state of adaptation planning for the Port of Rotterdam by focusing on the key choices made by the Dutch national government and the City of Rotterdam. Selecting a climate change scenario, adaptation goals, decision-making methodology, adaptation actions, implementation timeline, and finally, capital funding sources are the key choices these policy-makers made, or will make, when planning to adapt to climate change. The case study of the choices made for the Port of Rotterdam will support the development of an adaptation planning framework for U.S. Navy ports.

4.2. Choosing a Climate Change Scenario

Other than accepting climate change as an irrefutable fact, choosing a climate scenario for the Port of Rotterdam was the first key adaptation choice made by the Dutch authorities. Choose a climate change scenario which predicts too much sea level rise and extreme weather, and unnecessary infrastructure investments may be made. Choose a scenario which is too limited, and climatic changes, such as sea level rise, may occur too quickly for adaptation to occur, forcing the Dutch to adapt reactively and incurring higher human and economic costs (Kalra and Bonzanigo 2014).

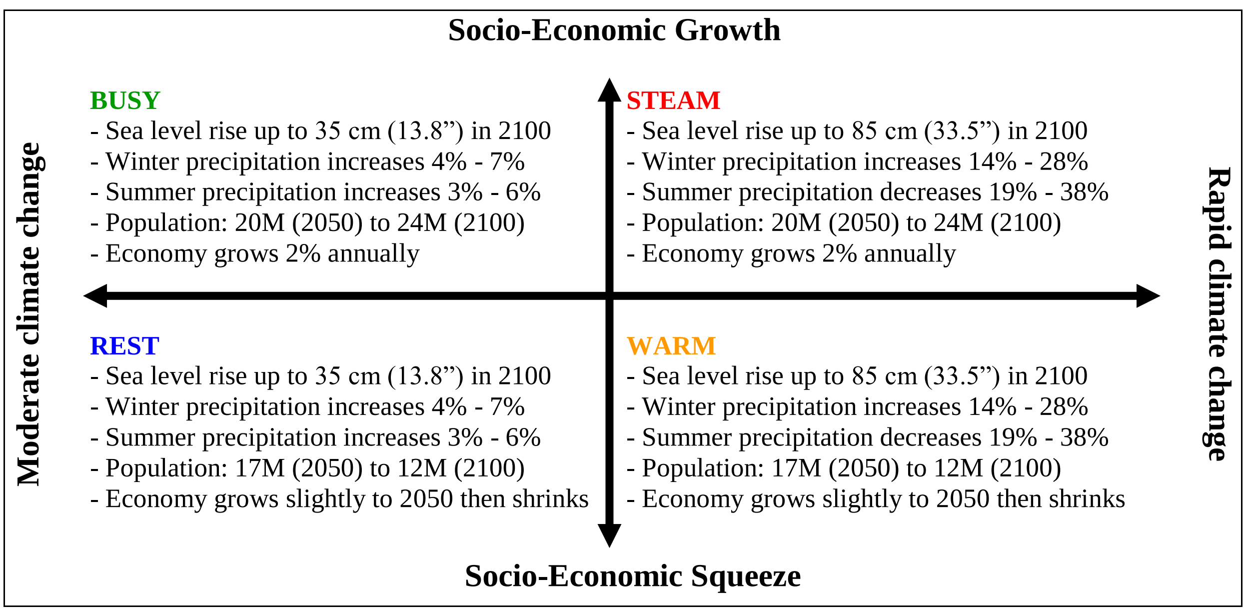
4.2.1. Climate Change Scenarios

Four climate scenarios, originally developed in 2006 by the Royal Netherlands Meteorological Institute (RNMI),[25] predicted sea level rise of 35 to 85 cm (14” - 33.5”) (relative to 1990) in 2100 (Van den Hurk *et al* 2006). The national adaptation program for The Netherlands, the Delta

[25] The national reference center in The Netherlands for weather, the climate, and seismology.

Program, combined these predictions with socio-economic models to produce the so-called "Delta Scenarios" upon which climate change planning in The Netherlands is currently based (Ministry of Infrastructure 2012). Figure 4.1 illustrates the Delta scenarios, including anticipated sea level rise (Ministry of Infrastructure 2012). RNMI updated its climate scenarios in 2014, resulting in a 5 cm increase in the maximum predicted sea level rise by 2100, but no increase in the minimum predicted sea level rise (Ministry of Infrastructure 2014). Planners for the City of Rotterdam and the national government considered the changes to be too minor to merit changing the Delta scenarios (Van Barneveld 2014; Ministry of Infrastructure 2014).

Figure 4.1. The Dutch Delta Scenarios
(Adapted from Ministry of Infrastructure 2012a, 35)



Notably the Dutch government explicitly chose to not assign a probability distribution to the four scenarios (Ministry of Infrastructure 2014). By default, this means the national authorities must assume each scenario is equally likely to occur, and all potential adaptation actions must be compared against all scenarios to evaluate robustness (Ibid.). Although Lempert and Schlesinger

(2000) would judge this use of climate scenarios to be economically inefficient, Dutch officials view the scenarios as helping them make the right adaptation decision at every stage of the adaptation process. Adaptation plans are structured so the Dutch can adjust their decision-making over time based on which climate scenario proves to be most accurate (Ministry of Infrastructure 2014).

The City of Rotterdam relied primarily upon a moderate climate change scenario, “Busy,” rather than all four scenarios equally, when developing the 2012 *Rotterdam Climate Adaptation Strategy* (Van Barneveld 2014). As the models for sea level rise in 2100 still include substantial uncertainty, city planners felt the need balance the security of the city and the port against the potential for over-investment in infrastructure, especially amidst an ongoing economic recession in The Netherlands (Van Barneveld 2014). Although the City of Rotterdam did not select the scenario with the least amount of climate and economic change overall – that would be “Rest” – they nevertheless chose the Delta Scenario with minimum level of sea level rise. However, Rotterdam city planners did compare the city’s adaptation plan to the “Rest” and “Steam” scenarios to ensure adaptation plans could be sped up or slowed down based on the speed of climate change (Van Barneveld 2014). The Port of Rotterdam Authority, on the other hand, is not focused at this time on the risks presented by any climate scenario, and does not seriously consider climate scenarios when making infrastructure decisions (Van Barneveld 2014; Kuipers 2014; Eisma 2014; Tieman and van ‘t Noordende 2014).

4.2.2. Port Infrastructure At Risk Due to Climate Change

As suggested by Scott *et al* (2013), a reasonable next step after selecting a climate scenario is to conduct a vulnerability assessment of infrastructure and functions at risk due to projected climate changes. The Port of Rotterdam Authority has not conducted a comprehensive assessment of infrastructure and port function vulnerable to climatic shifts (Eisma 2014). This policy gap has apparently occurred due to the perception of the Authority that the port is "safe enough" (Eisma 2014; Van Barneveld 2014; Tieman and van 't Noordende 2014; Kuipers 2014). Overall, the Port of Rotterdam Authority estimates the current flood risk to any area of the port is no worse than 1:1,000 (Van Rinske 2010).

This rather complacent position is contradicted by the simple fact that the Port of Rotterdam is built entirely outside of the dikes and inherently vulnerable to sea level rise and storm surge (Molenaar *et al* 2010). In the past the risk of storm surge to port infrastructure was clearly recognized. Sections of the port constructed since 1946 have been elevated to an elevation of 4.0 to 5.0 meters above sea level (Eisma 2014) and are reportedly at "extremely low" risk of flooding for many decades (Van Peijpe *et al* 2012). A recent study using extreme climate scenarios (sea level rise of 0.60 meters in 2050 and 1.3 meters in 2100) found flood risks to port areas behind the Maeslant barrier increased dramatically (Huizinga 2010). Flood risk to liquid bulk storage of fuel and other hazardous substances, generally located in the most protected areas of the port, may increase from 1:4,000 at present to 1:100 in 2100 under certain climate scenarios.

The older areas of the port, which are built at an average elevation of +3.5 meters NAP, are protected by a partial dike and the Maeslant storm barrier, which closes whenever storm surge of at least +3.0 meters NAP is anticipated. At this time Dutch authorities expect to close the barrier every 12 years, but by 2080 “Steam” scenario sea level rise may necessitate closing the barrier at least annually for flood protection (Van Peijpe *et al* 2012). Although originally intended to have a failure probability of 1:1,000, the Maeslant barrier’s failure rate is now estimated to be 1:100 (Huizinga 2010). Over time this will increase the annual flooding risk of the lowest areas of the port from more than 1:1,000 to 1:100, the protection rate afforded by the Maeslant barrier (Huizinga 2010).

The City of Rotterdam is concerned about flooding which might occur if the barrier does not function as designed (Van Barneveld 2014). If a storm surge of the same height as the infamous 1953 flood (+4.55 meters NAP) were to occur in Rotterdam without a functioning barrier, the consequences to the port and city would be catastrophic. Although it has only occurred once in the recorded past, sea level rise would make this high water level – or even higher – a more common occurrence. The storm surge barrier is expected to close with greater frequency in the future, which in turns increases the odds the barrier will not function properly when it is most needed. Dutch engineers did attempt to prepare for sea level rise by designing the barrier to accommodate up to 50 cm (19.7”) of sea level rise (Van Peijpe *et al* 2012). Unfortunately, resilience to sea level rise does not reduce the anticipated 1:100 failure probability of the barrier.

It is worth noting that the risk tolerance in The Netherlands for flooding of any kind is very low. City planners for Rotterdam acknowledge that compared to international flood control standards, no port infrastructure faces acute risks (Van Barneveld 2014). In comparison to San Diego, which is planning for a 100-year flood events in 2050 and 2100 (Hirschfeld and Holland 2012, 10), the minimum Dutch flood standard for any area protected by dikes is a 1,250-year flood event (Roos and Riedstra 2010; 6). As an area outside of the dikes, the port built in its own flood protection by elevating ground levels until estimated annual flood risk was reduced to at least 1:1,000, and frequently less.

The Port of Rotterdam Authority did support a limited vulnerability analysis by technical experts of the Maasvlatke 2 port expansion. Anticipating up to 2.0 meters of sea level rise, basic infrastructure on Maasvlatke 2 was built at an elevation of 5.0 meters NAP, and critical infrastructure (roads, chemical facilities) was built at an elevation of 5.5 meters NAP (Van Barneveld 2014; Lansen and Jonkman 2010). Due to the high elevation of the new port area, the chance of any flood at this time is very low (less than 1:10,000), and the flood duration would be short (Ibid.).

Little risk to human life was anticipated if a flood did occur, though the experts judged built infrastructure would incur substantial losses despite the short flood duration. The experts were most concerned about flooding of areas which store oils and other chemicals, and the potential for these hazardous substances to spread widely during a flood. A second major concern is electrical failure due to flooding, which would have cascading effects on mutually dependent systems, including water purification, sewer, telecommunications, roads, and railroads. This assessment only analyzed infrastructure at risk in the newest areas of the port built at high elevations. The study’s authors noted the need to perform a similar vulnerability assessment for areas of the port built at lower elevations.

This vulnerability assessment gap is clearly recognized by the city (Van Barneveld 2014), but less so by the port (Eisma 2014). Tunnels within the port have actually flooded within the last two decades due to heavy rainfall, causing serious disruption to port activities (Meeteren 2008; Rijnmond 2014). As sea levels rise this can be expected to happen with increasing frequency. Another key vulnerability is the port's electrical infrastructure, given its mutual importance to nearly every other system. The port is also home to two large, coal-fired power plants which provide electricity to the greater Rotterdam area (Kuipers 2014). Freshwater pipes in the port are not expected to be affected by flooding, but the underground sewer pumping station could be impacted directly by a flood, or indirectly by loss of power (Van Barneveld 2014). A final vulnerability of the port is crisis management and disaster response. In the opinion of each of the officials consulted in Rotterdam, this area of preparedness is lacking and represents an area of substantial vulnerability (Van Barneveld 2014; Tieman and van ‘t Noordende 2014; Eisma 2014).

4.3. Decision-Making for Climate Change Adaptation

4.3.1. Decision-Making Responsibility

Responsibility for climate change adaptation decision-making for the Port of Rotterdam is mixed. The most important decision-making bodies are the Port of Rotterdam Authority, the City of Rotterdam, the Province of South Holland, and the national government of The Netherlands, all of whom will all make decisions affecting the adaptation of the Port of Rotterdam to climate change. Smaller entities, such as the rail managers and utilities, will follow the direction of the various governments when adapting their infrastructure for climate change (Van Barneveld 2014).

The Port of Rotterdam Authority, as the landlord of the port, maintains roads and other general infrastructure through the Port Authority's capital improvement program (CIP) (Eisma 2014). In the future it is expected the Port Authority will also use its CIP to adapt general port infrastructure to climate change (Eisma 2014; Van Barneveld 2014). The facilities leased by companies on port land must comply with rules, such as allowable ground floor elevation or secondary spill containment, established by Dutch law and enforced by the Port Authority (Eisma 2014; Tieman and van 't Noordende 2014). Based on guidance from the Province of South Holland, the Municipality of Rotterdam's zoning law specifies minimum ground floor elevations for all infrastructure within city limits, a range of authority which extends to the port (Van Barneveld 2014).

Generally speaking, the Dutch national government views residential and commercial areas outside of the dikes to be "on their own" for flood risk management. Since the Port of Rotterdam sits entirely outside of an enclosed dike ring, purportedly this policy would be strictly applied to the Port of Rotterdam Authority, an incorporated public company. City staff certainly desire for the Port of Rotterdam Authority to adapt to climate change using Port Authority funds (Van Barneveld 2014). City planners, as well as the national government to a certain extent, also recognize each level of government bears a burden of social responsibility to its citizens. Both view the potential damage which might result from a flood-borne chemical spill to be too great a risk to allow the Port of Rotterdam Authority to fall short with regards to climate change adaptation (Van Barneveld 2014). The Dutch government has also been receptive to arguments that the Port of Rotterdam is a national economic asset which The Netherlands cannot afford to have badly damaged (Van Barneveld 2014; Eisma 2014). It is anticipated the national government will provide funding to assist the port with climate change adaptation (Van Barneveld 2014). With the funding, of course, will likely come demands to have greater input on adaptation decision-making for the port itself.

Aside from the aforementioned social responsibility, the Dutch national government does retain some statutory responsibility for climate change adaptation at the Port of Rotterdam. Rijkswaterstaat, the national infrastructure authority, is responsible for the Maeslant and Hartel storm surge barriers, the primary dike which connects the barriers, and a national highway passing through the port (Van Barneveld 2014). In addition to protecting the city of Rotterdam, the barriers and dike shield approximately one-half of the port against high water.

4.3.2. Decision Support Tools for Climate Change

Social cost-benefit analysis (CBA) is the standard analytical method used in The Netherlands to inform large-scale infrastructure decisions, such as construction of the Maeslant storm surge barrier and the Maasvlatke 2 expansion of the port (Van Barneveld 2014; Kuipers 2014). The results of a CBA are not the decisive factor for major infrastructure decisions, but are instead evaluated in conjunction with the political and legal aspects of any decision (Van Barneveld 2014). In the case of the Delta Program, officials also completed an integrated problem analysis to complement the social CBA (Van Barneveld 2014).[26] Cost-effectiveness analyses have also been completed for the Delta Program (Ministry of Infrastructure 2014), though it is unclear which costs were so analyzed and how that analysis was used.[27]

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[26] Integrated problem analysis (IPA) is an interdisciplinary approach frequently used to evaluate the causes and effects of negative environmental impacts. The general steps are: problem definition, impact assessment, root cause analysis, and prioritization of causes (see Francis et al (2002) for a demonstration of IPA).

[27] Cost-effectiveness analyses compare the costs of actions which achieve the same results, but have differing costs.

A cost-benefit analysis is not required for development of a climate change strategy, in the opinion of the Rotterdam city official interviewed for this project. The city did not complete a comprehensive CBA prior to development of Rotterdam Climate Adaptation Strategy (Van Barneveld 2014). Instead city planners decided to publicize an adaptation strategy first, then develop detailed financial estimates later. City officials feared affixing a price to proposed adaptation measures would send the wrong message to residents and businesses regarding the safety and long-term economic viability of the city (Van Barneveld 2014). Rotterdam planners do not neglect cost analysis altogether; smaller adaptation projects have already undergone such scrutiny. The Rotterdam Societal Cost-Benefit Analysis is scenario-based tool for smaller projects, comparing the net effect of society if an adaptation measure is implemented versus a "null" or no action alternative (Rotterdam Climate 2014).

The Port of Rotterdam Authority decision-making methodology for infrastructure varies, though life cycle analysis is one of the most commonly used methods (Eisma 2014). The Port of Rotterdam Authority has not chosen a methodology to use for making climate change adaptation decisions (Eisma 2014).

4.4. Climate Change Adaption Strategy

4.4.1. Plans and Policies Affecting Port Adaptation Strategy

Foremost among policies affecting adaptation planning for the Port of Rotterdam is the "Rotterdam Climate Proof" program, which was approved by the Rotterdam City Council in 2008 (Van Peijpe *et al* 2012). Rotterdam Climate Proof (also referred to as the "Rotterdam

Climate Initiative" (RCI)), set forth three main objectives for the city to accomplish by 2025 (Van Peijpe *et al* 2012):

1. Research the predicted effects of climate change.
2. Reduce CO_2 emissions by 50% and make the city 100% resilient ("climate-proof") to climate change.
3. Market the Rotterdam Climate Initiative to the world at-large.

Gradually the RCI progressed, eventually resulting in the *Rotterdam Climate Change Adaptation Strategy* in 2012. Although the strategy in general applies to the port, the city also included a section detailing adaptation measures the city expects the port to implement where appropriate (see section 4.5.1). The Municipality of Rotterdam also specifics zoning requirements for new or redeveloped buildings outside of the dikes – which includes all of the port area – to be built at a minimum elevation for flood protection, both from the sea and from the rivers (Eisma 2014; Van Barneveld 2014).

The Delta Program was launched by the Dutch government in 2011 to prepare The Netherlands for the effects of sea level rise (Ministry of Infrastructure 2012). The program focuses on flood risk management for The Netherlands via primary dikes, flood barriers, spatial planning and disaster response.[28] The Port of Rotterdam is affected by the Delta Program decisions on replacement of the Maeslant and Hartel barriers as well as the primary dike connecting the barriers. Rather than specify a necessary height for every dike ring (as had been done in The Netherlands for decades), the Delta Program instead directed the establishment of multi-layer flood risk management for all areas (Ministry of Infrastructure 2014):

[28] Ironically for a country with a surfeit of water, freshwater security is also one of the Delta Program focus areas.

1. Preventive measures to limit flood probability.
2. Limit development in flood-prone areas.
3. Effective disaster and crisis management response to flooding.

In some cases this will mean raising dikes to protect large swathes of homes and businesses. In the case of the Port of Rotterdam it will likely mean more localized flood control measures such as those discussed in section 4.5.1.

4.4.2. Process to Develop Adaptation Strategy

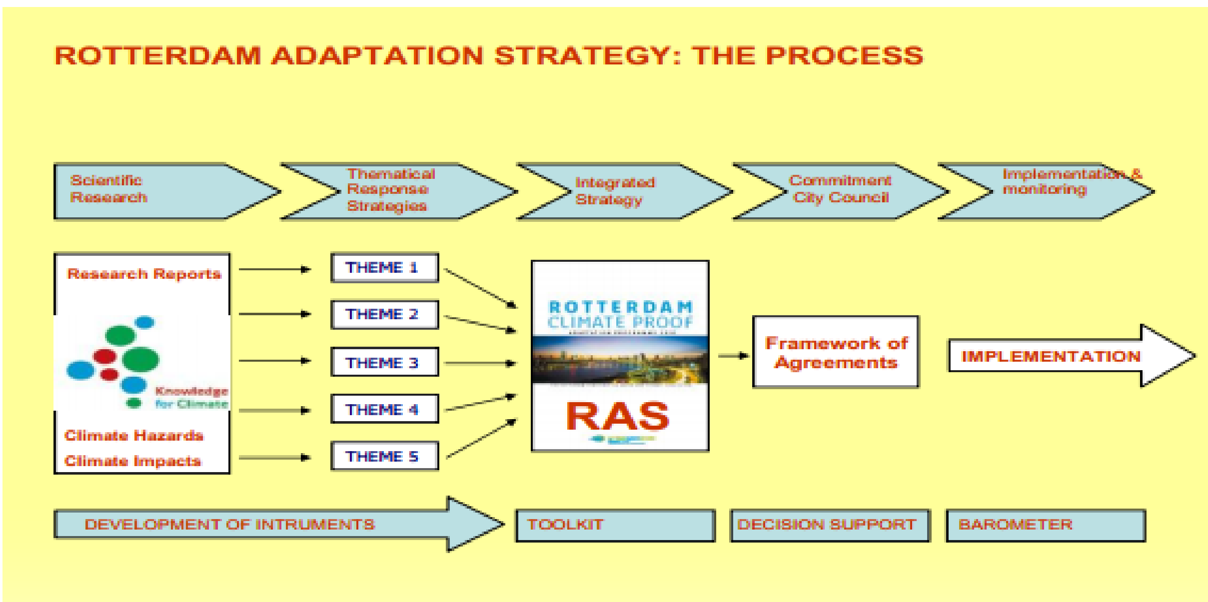
The primary parties collaborating on a port-specific adaptation strategy are expected to be the Port Authority, City of Rotterdam, Rijkswaterstaat, and Deltalinqs (Eisma 2014; Van Barneveld 2014).[29] Given the commercial nature of the port, Port Authority officials are advocating for an adaptation strategy based on 2050, rather than the city's focus on 2100 (Eisma 2014). This fundamental disagreement between the two entities on planning horizons has not been resolved.

Given the unique challenge of climate change adaptation, City of Rotterdam staff relied upon a web of policy actions, rather than a formal strategy development process, to build public awareness and political engagement for a climate change adaptation strategy (Van Barneveld 2014). The establishment of the Rotterdam Climate Proof program in 2008 initiated the process, which was then propelled by the national Delta Program (2011 to present) as well as the Knowledge for Climate research effort (2008-2014). In 2012 the Province of South Holland, which regulates urban planning policy within the province, began requiring municipalities to

[29] Rijkswaterstaat is the department of the Dutch Ministry of Infrastructure and the Environment charged with maintaining the primary flood defenses and national infrastructure (i.e., national highways) of The Netherlands. Deltalinqs is the corporate association of Port of Rotterdam employers.

build adaptively to the effects of climate change (Van Barneveld 2014). In doing so South Holland adopted the “Busy” climate scenario for policy development purposes. City of Rotterdam planners followed the lead of the province and also adopted the same scenario for 2100 (Van Barneveld 2014). Ultimately this resulted in the 2012 release of the *Rotterdam Climate Change Adaptation Strategy* (see Figure 4.2).

Figure 4.2. Rotterdam Adaptation Strategy development
(Image: Döpp, Molenaar, and Pool 2012, 18)



With the 2014 publication of the finalized Delta Program, the Port of Rotterdam Authority finally initiated preparatory work to develop a climate change adaptation strategy (Eisma 2014). Although Port of Rotterdam Authority clearly could have begun developing adaptation plans at the same time as the City of Rotterdam, the Port Authority considered making adaptation plans prior to finalization of a national climate change adaptation program (i.e., the Delta Program) to be premature and potentially economically wasteful (Eisma 2014). Conversely, City of Rotterdam officials believed they could not afford to wait for a national adaptation program

(Molenaar *et al* 2010; Van Barneveld 2014). City authorities intended to develop an adaptation plan first, then adjust when the plans and policies of the Delta Program were published.

4.4.3. Adaptation Strategy

Overall, the adaptation strategies developed by the City of Rotterdam and Dutch government are a combination of protection and accommodation. The adaptation options of do-nothing or retreat are not considered options at all (Van Peijpe *et al* 2012). Planners from the national government and the city fully intend for Rotterdam to adapt when opportunities occur, implementing flexible, no-regret measures without retreating in the face of rising sea levels (Van Barneveld 2014; Van Peijpe *et al* 2012). With this underlying philosophical foundation, Rotterdam planners constructed the Rotterdam Climate Adaptation Strategy with four pillars (adapted from Van Peijpe *et al* 2012):

- Maintain and strengthen Rotterdam's existing water management system, including storm surge barriers, dikes, sewers, and pumping stations.
- Utilize the full urban environment for both small- and large-scale adaptation measures.
- Combine adaptation objectives with needs of other entities affected by climate change.
- Ensure adaptation efforts add value to the environment, economy, and society.

The goals in the City of Rotterdam's Climate Adaptation Strategy are based on the foundational concepts listed above, and apply equally to the city and the Port of Rotterdam (adapted from Van Peijpe *et al* 2012):

- Flood protection for the city, businesses, and residents.
- Resiliency to extreme rainfall or drought.

- Safeguard the Port of Rotterdam without blocking access.
- Public awareness and support of climate change adaptation programs.
- Multi-functional adaptation (i.e., adaptation projects should also fulfil societal and economic priorities).

As noted previously, the port has not established specific climate adaptation goals, but anticipates doing so as part of the strategy development process (Van Barneveld 2014; Eisma 2014). All stakeholders consulted for this project expect the Port of Rotterdam Authority's strategy to continue the strategy of opportunistic adaptation initiated by the city.

4.4.4. Stakeholder Engagement on Adaptation Strategy

The city planners led the strategy development process for Rotterdam as well as engagement with stakeholders (Van Barneveld 2014). A strong mayor and solid city council support enabled city planners to push forward aggressively with an adaptation strategy (Van Barneveld 2014). The Delta Program was also key to raising awareness of the need to adapt, providing a framework for discussions and the making of policy decisions (Van Barneveld 2014). A key element of stakeholder engagement was using pictures and drawings, rather than text alone, to create a storyline for political and public consumption (Van Barneveld 2014). Planners understood the threat posed by climate change was too far in the future to rely upon dry policy papers to make their case. Evocative drawings of what might happen as a result of progressively higher sea levels, and the steps the city planned to take to avoid the associated negative effects of climate change, were important to helping people comprehend the otherwise remote threat of sea level rise and other climatic changes.

4.5. Adaptation Actions

4.5.1. Adaptation Actions

In recognition of the Port of Rotterdam's vulnerable position entirely outside of the dikes which protect the rest of The Netherlands, the land which the port occupies has, over time, been elevated to a height of three to five meters above sea level (Eisma 2014; Van Barneveld 2014). Raising the port was not intended to prepare for climate change, but merely to avoid flooding of the level experienced by The Netherlands in the past. Only with the recent expansion of the port (construction of Maasvlatke 2, completed in 2013) did the port allow for the danger posed by sea level rise (Eisma 2014; Van Barneveld 2014). Yet as of December 2014 the Port of Rotterdam Authority has not identified a program of climate change adaptation measures for the port as a whole (Van Peijpe *et al* 2012).

Although Dutch authorities may not have realized it when the Maeslant storm surge barrier was built in the 1990s, designing the barrier with the ability to accommodate 50 cm (19.7") of sea level rise bought Rotterdam 40-50 years to make a decision on its replacement. In a related measure which affects the Port of Rotterdam, the Dutch Ministry of Infrastructure and the Environment plans to reduce the failure probability of the Maeslant storm surge barrier by 2028, and replace the barrier altogether by 2100 (Van der Veer 2014).

The city's 2012 *Rotterdam Climate Change Adaptation Strategy* identifies generic actions to be implemented on a location- and function-specific basis. The fact that the city has specified actions already is partly due to the city's aggressive posture regarding climate change, and partly due to the exponentially higher costs the city is projected to experience if large-scale flooding were to occur. Table 4-1 is an unprioritized list of the city's chosen actions.

Table 4-1. Port of Rotterdam adaptation actions
(Adapted from Van Peijpe *et al* 2012)

Adaptation Action	Purpose	Responsible Party
Terp construction[30]	Protection of bulk goods stored outside.	Port businesses at risk.
Wet-proof construction	Protection of goods stored inside.	Port businesses at risk.
Small compartment dikes	Hazardous material protection.	Port businesses at risk.
Elevated infrastructure (e.g., roads and railroads)	Guarantee port accessibility.	Initiated by the Port of Rotterdam Authority.
Ecological structures (i.e., pipelines)	Mitigate urban heat island effects.	Initiated by the Port of Rotterdam Authority.
Dry-proof construction and floodwalls	Security of critical infrastructure.	Electrical Utility, Water Utility, Water Board, City of Rotterdam, Port of Rotterdam Authority, Ministry of Infrastructure and Environment, Province of South-Holland.

Unofficially, the City of Rotterdam is also advocating for flood safety considerations (and sea level rise) to be incorporated into the standard environmental permitting process for infrastructure development (Van Barneveld 2014; Eisma 2014). In the future, city planners also expect to adjust required first floor building elevations upward to prepare for sea level rise resulting from climate change (Van Barneveld 2014). Planners already differentiate between a design elevation for basic infrastructure and a design elevation for vital infrastructure and infrastructure for hazardous materials, including chemicals and fuels. More differentiation

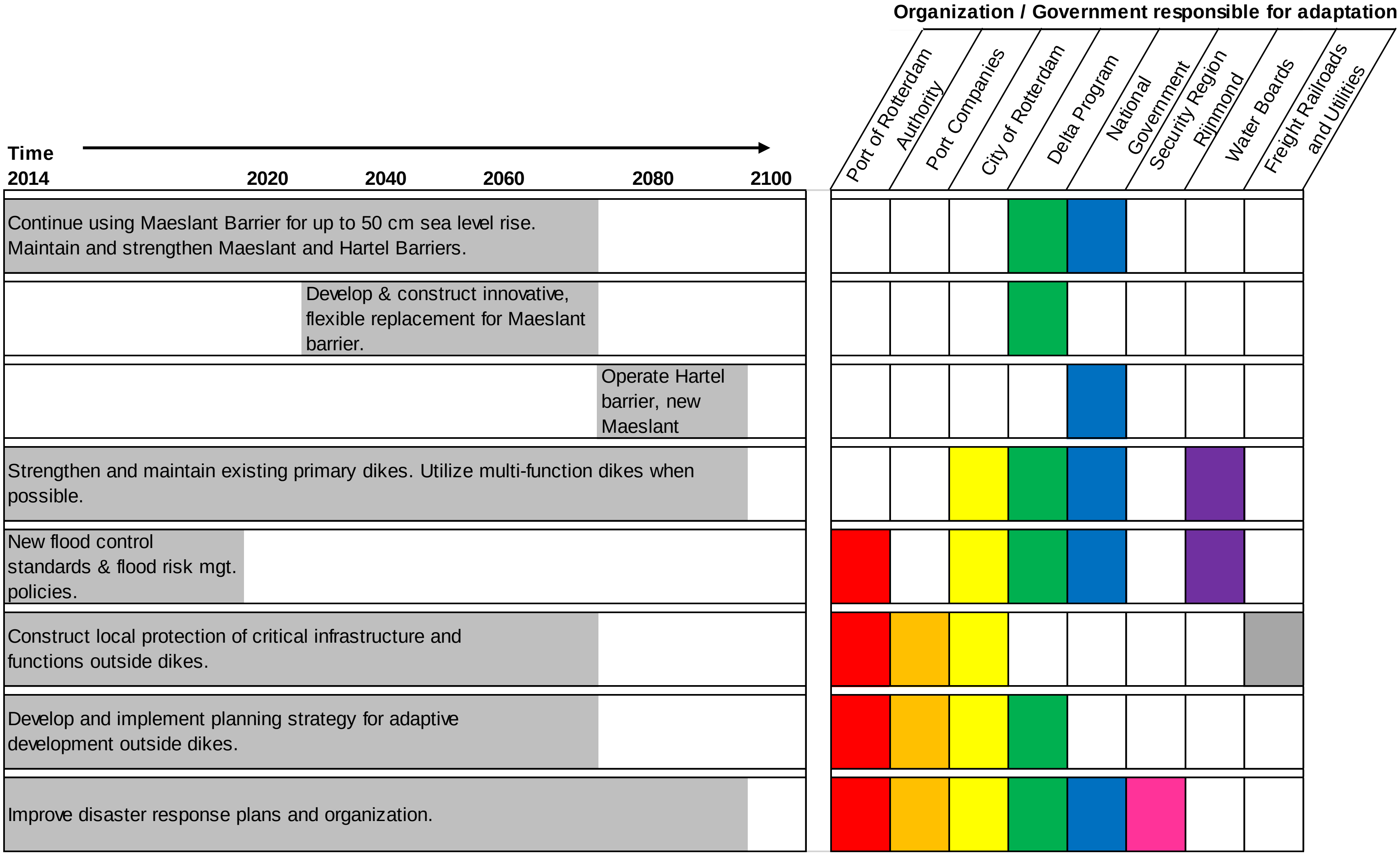
[30] Terps are elevated mounds or platforms of earth built to protect people, goods, and buildings from flooding from rivers or high tides. The Dutch have been constructing terps for millennia (Bazelmans *et al* 2012).

between design levels, resulting from a risk-based methodology, may be used for infrastructure on the port (Ibid.).

In addition to the chart of general adaptation actions above, the City of Rotterdam has also developed a 100-year water safety plan for the city and the port (see Figure 4.3), which explains which large-scale adaptation measures are planned, when the measures will be implemented, and which organization (port, city, electrical utility, etc.) is responsible for implementation (Van Barneveld 2013). What the plan does not do is explain how these organizations might pay for adaptation to climate change; just that they will. It is important to note the plan is not binding upon outside organizations since it is a municipally developed document.

A key highlight of the city's plan is its flexibility; depending on the rate of sea level rise, passage of time, and socio-economic changes within the city (i.e., population growth and/or port expansion), implementation of specific adaptation measures can be accelerated or slowed as needed. Some adaptation actions, such as adaptive building outside the dikes and improving crisis management/disaster response capabilities, will begin immediately and continue far into the future, regardless of the rate of climate change.

Figure 4.3. Detailed 100-Year Climate Change Adaptation Plan for Rotterdam
(Adapted from Van Barneveld 2013, 28)



The largest, and most difficult, part of the city's plan is the expected replacement of the major storm surge barriers in The Netherlands. Completing the original Delta Project took approximately 60 years; replacing the storm surge barriers is expected to require an equivalent period of time (Van Barneveld 2013). Under the "Warm" and "Steam" climate scenarios 50 cm (19.7") of sea level rise will occur by approximately 2080. Increases in sea level over 50 cm (19.7") are expected to require closure of the Maeslant barrier more than once per year, a closure rate deemed unacceptable by the city and port (Van Barneveld 2013). Working backwards (and thinking optimistically), planning and construction of a more flexible replacement of the Maeslant barrier must begin in approximately 2040 to ensure it has been completed by 2080 (Van Barneveld 2013). The virtue of drafting an adaptation plan now is Dutch authorities are well-prepared to make a decision on replacing the Maeslant barrier based on the variables of time, rate of sea level rise, and speed of socio-economic change (Van Barneveld 2013).

4.5.2. Supporting Data for Decisions

Replacing the Maeslant barrier is the highest cost item in the adaptation plan, thus meriting the most detailed review. Supporting analysis for other recommendations in the Rotterdam Adaptation Strategy was supplied by the Knowledge for Climate research program using cost-benefit analyses (Van Barneveld 2013). The key supporting study for the future of the Maeslant barrier was also a cost-benefit analysis (with a fixed discount rate) conducted by Dutch authorities (Van Barneveld 2013). Numerous options were reviewed, including doing nothing, constructing a dam with locks, and removing the Maeslant barrier without building a replacement. Doing nothing and building a flexible replacement barrier for the Maeslant barrier both yielded slightly positive cost-benefit analyses; all others ranged from slightly negative to dramatically negative.

This small difference is the reason given for planning for a replacement for the Maeslant barrier beginning in 2040 (Van Barneveld 2013). A robustness analysis of the CBA discount rates was not performed, thus it is unknown if replacing the barrier is a “good” decision for the widest range of possible futures. Given the extended decision period leading up to a final decision on the barrier, plentiful opportunity exists for the city to conduct detailed sensitivity analyses of the plan to replace the Maeslant barrier. Essentially, the Dutch have given themselves 25 years until they must start planning to replace the barrier, reducing their decision time horizon on the Maeslant barrier from 60+ years to approximately 40 years. This reduction of uncertainty is key given the high cost and complexity of replacing of the barrier.

4.5.3. Incorporation of Adaptation Actions into Capital Improvement Plan

The Port of Rotterdam Authority utilizes five-year plans (with annual updates) to manage capital improvements within the port’s boundaries (Eisma 2014). The Port Development Department is responsible for building projects, and the Asset Management Department maintains the facilities once they are constructed. The Port Authority generally pays for capital improvements via berthing fees and leasing port facilities, although in exceptional cases, such as the construction of Maasvlatke 2, a $2.9 billion expansion of the port, the Authority borrows funds from the city and national government to complete the work (Eisma 2014).

None of the actions listed in the general Rotterdam Climate Adaptation Strategy, or the detailed 100-year adaptation plan, have been systematically included in capital improvement plans for the City of Rotterdam or the Port of Rotterdam (Van Barneveld 2014; Eisma 2014). Instead, the city has relied upon small-scale, one-time demonstration projects, such as floating pavilions and multi-functional urban water storage projects, which were built when an opportunity arose rather than as part of a formal capital improvement plan (Van Barneveld 2014). At this time the city, and certainly not the port, does not have a formal method for ensuring climate adaptation is considered as a formal criteria when evaluating potential capital improvement projects (Van Barneveld 2014; Eisma 2014). The national government, on the other hand, coordinates – and frequently funds – the largest adaptation projects, such as replacement of the barriers and strengthening of primary dikes, as a program separate from regular capital improvements.

4.6. Adaptation Finance

As the decision-making responsibilities are mixed, so are the sources of financing for climate change adaptation at the port. The Port of Rotterdam Authority is accountable for adaptation of general port infrastructure using funds collected from port companies, though the burden of social responsibility felt by the City of Rotterdam and national government may compel them to also contribute to the expense of adaptation at the port (Van Barneveld 2014; Eisma 2014). Funding sources for climate change adaptation are not identified in city and port policy documents.

Rijkswaterstaat, the Dutch national infrastructure agency, pays for maintenance and improvements to flood control barriers and primary dikes via the national Delta Program.

Funding for the Delta program is guaranteed through 2028 (Ministry of Infrastructure 2014). Replacement of the barriers would occur long after 2028, though, necessitating additional financial commitments in the future by the national government. Rijkswaterstaat also bears adaptation responsibility for the national highway passing through the port (Van Barneveld 2014).

The railroad infrastructure companies, KeyRail and ProRail, will pay for any necessary adaptation actions to railway infrastructure (Van Barneveld 2014). The electrical utility will also be required to ensure its facilities are resilient to negative climatic effects. On a smaller scale, individual companies will be responsible for preparing their leased facilities for climate change (Van Barneveld 2014; Eisma 2014; Tieman and van 't Noordende 2014).

4.7. Adaptation Planning Timeframe

The City of Rotterdam's stated intent is for the city – and also the port – to be "100% climate-proof" by 2025 (Van Peijpe *et al* 2012). Considering it is now 2015, one might reasonably assume the city and port are well on their way to becoming resilient to the effects of climate change. However, as acknowledged by city staff, choosing 2025 as a deadline for climate readiness was a political goal intended to build public support rather than an attainable objective (Van Barneveld 2014). Rhetorically, how can a city possibly become "climate-proof" if continuous adaptation to climate change is a perquisite of a sustainable port and city?

Setting philosophical questions aside, the general timeline for water safety for Rotterdam described in section 4.4.1 provides a more realistic overview of climate change adaptation for the next 100 years, rather than limiting planning to the next decade. The century-length strategy represents a substantial improvement from the initial list of adaptation actions listed in the 2012 Rotterdam Adaptation Strategy, which were generic in nature and did not specify when adaptation actions would occur. The timeline specified when adaptation actions will be initiated as well as when major decisions, such as choosing in 2040 to replace the Maeslant barrier sometime between 2080 and 2100, must be made on expensive adaptation actions.

The Dutch government's adaptation plans also call for continual adaptation to the year 2100 and beyond (Ministry of Infrastructure 2014). Although certain measures are specified for implementation at a given time, the plan also allows for variance if climate change is faster or slower than predicted by the Delta scenarios. The Port of Rotterdam, on the other hand, only seeks to plan capital improvements up to the year 2050, and so far has seen no need to develop an adaptation plan (Eisma 2050). As noted before, this decision is short-sighed given the long service lives of major infrastructure systems and components (Hallegatte 2009).

4.8. Status Report: Implementing Adaptation Plans

Notably, the 100-year adaptation timeline from the City of Rotterdam also included numerous actions by the Delta Program and the Dutch national government, all of which are outside the control of the city and the port. Still, progress is being made by these organizations; some major adaptation actions, such as raising of the dikes in selected locations based on a new flood risk management strategy, are even slated to occur in the next few years (Ministry of Infrastructure 2014).

Although large-scale adaptation in Rotterdam is not yet underway, several pilot projects have been executed across the city to highlight the need for resiliency to sea level rise, and for temporary water storage during the increasingly frequent high intensity rainfall events (Rotterdam Climate 2014). Adaptive construction has also begun in areas outside of the dikes, though little progress has been made so far (Van Barneveld 2014).

No comprehensive action or planning to prepare for climate change has been formally undertaken by the Port of Rotterdam Authority. Although not stated in policy documents, in public presentations the port has emphasized a conservative policy of opportunistic adaptation: when opportunities occur, implement flexible, no-regret adaptation measures which make financial sense (Van der Meer 2011). So far that strategy has only resulted in building Maasvlatke 2 to an elevation able to accommodate up to two meters of sea level rise (Van Barneveld 2014; Eisma 2014). No other major adaptation measures have been implemented.

The other action taken thus far by the Port of Rotterdam Authority is to collaborate with the City of Rotterdam and the national government on a planned pilot project within the “Botlek” area of the port. The research-focused project will use risk-based methodology to conduct a vulnerability assessment of the Botlek area, then construct a decision-making framework based on the level of risk authorities are willing to accept (Eisma 2014; Van Barneveld 2014). This framework will guide the Port of Rotterdam Authority what actions to take, and when to take them (Eisma 2014). Port officials contend that if the strategy produces any “quick wins” they will attempt to implement those actions immediately (Eisma 2014). Otherwise, a prioritized list of adaptation actions would be incorporated into the port’s capital improvement plan for execution at a later date (Eisma 2014). Adaptation actions required of individual companies would also be fashioned into a plan for implementation (Eisma 2014).

At this time the Rotterdam city planners do not intend to revisit and re-issue the city's climate adaptation strategy on a regular basis (Van Barneveld 2014). City officials report climate adaptation has been sufficiently incorporated into the city's regular planning functions such that a regular review of the city's plan is not required (Van Barneveld 2014). The on-going discussion surrounding the national Delta Program helps maintain awareness within the city. Furthermore, issuance of the annual Delta Program report may provide a natural moment to evaluate the city's progress towards their "climate-proof" goal (Van Barneveld 2014). Port of Rotterdam Authority officials suggest that although they do not have an adaptation plan now, re-evaluation of adaptation plans would likely occur every 10 years in conjunction with the regular updates of the Port Authority's strategic plan (Eisma 2014).

4.9. Summary of Adaptation Planning Choices

Climate change, and sea level rise in particular, poses a distant threat to the Port of Rotterdam (Eisma 2014; Van Peijpe *et al* 2014; Van Barneveld 2014). Unsurprisingly, the Port of Rotterdam Authority has resisted planning to adapt to climate change, and has made no choices in this regard. In the absence of action by the port, the City of Rotterdam and the Dutch national government are pushing forward with complementary plans for climate change adaptation which will give the Port of Rotterdam Authority no choice but to adapt, too. Table 4-2 summarizes the adaptation choices made by Dutch officials for the Port of Rotterdam.

Table 4-2. Summary of Adaptation Choices for the Port of Rotterdam

Adaptation Choice to be Made	Dutch National Government's Choice	City of Rotterdam's Choice	Port of Rotterdam's Choice
Climate Scenario	No scenario favored. 35 cm (13.8") - 85 cm (33.5") sea level rise in 2100	"Busy" scenario with 35 cm (13.8") sea level rise in 2100	None chosen.
Decision Support Tool	Cost-benefit analysis (CBA) with fixed discount rate. Also integrated problem analysis and cost-effectiveness analysis.	None used for development of citywide climate change adaptation strategy. Rotterdam Societal Cost-Benefit Analysis for small projects.	Life-cycle analysis (stated preference).
Strategy	Protection and limited accommodation. Flexible implementation.	Protection and accommodation. Flexible implementation	None chosen.
Actions	"Hard" protection measures (dikes, barriers). Limited "soft" accommodation (increased risk tolerance).	New flood control and risk management policies. Local protection of critical infrastructure and functions. Adaptive development in flood-prone areas. Improve disaster response.	None chosen.
Financing	Delta Program budget through 2028.	Annual city budget.	Companies using port, city & national governments, utilities.
Planning Timeline	2100 and beyond	2100 and beyond	2050 (stated preference)

5. Adaptation Planning for the Port of San Diego

5.1. Introduction

The *Sea Level Rise Adaptation Strategy for San Diego Bay* represented a collaborative effort of San Diego Bay-area governments and organizations (including the Port of San Diego) to address the risks represented by climate change.[31] The regional climate adaptation strategy, one of the first developed in the US (Hirschfeld and Holland 2012), was intended to inform subsequent adaptation plans developed by the member organizations. Although not binding upon the steering committee membership, the plan provided a framework from which more detailed plans could be developed. The Port of San Diego is in the process of developing a climate change adaption plan based in part on the 2012 strategy, though the plan is years from completion (Hooven 2015). Since the Port of San Diego Board of Port Commissioners is appointed by the member city governments, one would expect linkages between the Port's in-progress plan, the *Sea Level Rise Adaptation Strategy for San Diego Bay*, and plans developed by the member governments. Unfortunately, city governments adjoining San Diego have not made much progress in regard to adaptation planning, either.

This chapter seeks to explain the process by which the Port of San Diego's adaptation plan is being developed, as well as the key choices port and city officials have made regarding climate change adaptation. Officials acknowledge climate change is a problem, but few definitive adaptation choices have been made to help the Port of San Diego and its member cities adapt.

[31] Members of the Public Agency Steering Committee for development of the adaptation strategy: San Diego Unified Port District, San Diego County Airport Authority, City of San Diego, City of Chula Vista, City of Coronado, City of Imperial Beach, and City of National City.

This case study of the choices made for the Port of San Diego will inform development of an adaptation planning framework for U.S. Navy port infrastructure.

5.2. Choosing a Climate Change Scenario

5.2.1. Climate Change Scenarios

The primary climate change effects of concern for San Diego Bay are sea level rise and the increasing regularity of storm surge events (Messner *et al* 2013). Other climatic changes anticipated include increasing drought and water shortage, consistently warmer temperatures, and more frequent and intense storms (Messner *et al* 2013). In particular, average temperatures in San Diego are expected to climb: 1.5°F to 4.5°F by 2050, and 3.0°F to 8.0°F by 2100 (Messner *et al* 2009, 12). Climate models do not agree whether precipitation in San Diego will increase or decrease as the planet warms (Ibid., 13).

Sea levels rose an average of 2.04 mm/year in San Diego from 1906-2008 (NRC 2012; 95). Based on that trend, as well as several climate models predicting escalating rates of sea level rise, the public agency steering committee for San Diego Bay elected to plan more conservatively for sea level rise. As shown in Table 5-1, the 2050 climate scenario includes 0.5 meters of sea level rise, and the 2100 scenario, 1.5 meters of sea level rise.[32] These figures are drawn from the high end of the National Resources Council sea level rise projections. The Port of San Diego is using these scenarios for planning purposes, though the level of risk officials are willing to accept will likely vary based on the area of vulnerability (Hooven 2015). For example, officials would not

[32] The State of California (2010, 4) initially recommended sea level rise scenarios for 2050 (10” to 17” or 26 to 43 cm) and 2100 (31” to 69” or 78 to 176 cm). In 2013 the State updated its guidance to recommend changing the ranges slightly for 2050 (now 12 to 61 cm or 4.7” to 24”) and 2100 (42 to 167 cm or 16.5” to 67”) (State of California 2013, 2).

object to a parking lot being flooded under extreme conditions in 2100, but inundation of critical transportation infrastructure may not be tolerated.

Table 5-1. Sea level rise scenarios for San Diego Bay (relative to 2000 baseline)
(Hirschfeld and Holland 2012, 10)

Year	Daily Conditions	Extreme Event
2050	0.5 m (20”) sea level rise	100-year extreme high water event plus 0.5 m (20”) sea level rise
2100	1.5 m (59”) sea level rise	100-year extreme high water event plus 1.5 m (59”) sea level rise

Utilizing relatively extreme climate scenarios is not a robust choice for planning purposes (Lempert and Schlesinger 2000), and may well result in economically inefficient adaptation choices. Additionally, the lack of substantial progress with regards to adaptation planning in the region is likely a result of political disagreement over baseline assumptions regarding future climate change. Instead, Kalra *et al* (2014) urge authorities to move past divisive climate assumptions and argue about more substantive matters: namely, discussing the relative merits of adaptation measures, and using those discussions to make robust decisions about climate change adaptation.

5.2.2. Port Infrastructure At Risk Due to Climate Change

The Port of San Diego faces numerous risks under the chosen climate scenarios, though the primary climate change-linked threat to the San Diego Bay area is flooding related to sea level rise: high tides, normal waves, storm surge, and El Niño-linked events (Hirschfeld and Holland 2012; Messner *et al* 2013). The Port of San Diego has not completed a comprehensive vulnerability survey of vulnerable infrastructure within the port’s planning jurisdiction, as recommended by Scott *et al* (2013), though this is planned for a future date (Hooven 2015).

From a general perspective, at-risk infrastructure systems surrounding the bay are documented in the *Sea Level Rise Adaptation Strategy for San Diego Bay* (see Table 5-2), and maps of future conditions along the bay clearly project inundation and flooding of large areas of land within the port's planning area of responsibility.[33] Notably, most of the systems and facilities at risk are owned by cities and utilities, though the Port of San Diego is responsible for maritime facilities, ecosystems, and public facilities.

Although this assessment did not specifically refer to any maritime or commercial infrastructure for which the Port of San Diego is responsible, port officials anticipate impacts to these systems from climate change in 2050 and 2100 (Hooven 2015). Port officials will be able to evaluate impacts with greater certainty after a detailed hydrodynamic model is prepared and run for San Diego Bay by the Scripps Institute of Oceanography (UPSD 2014). Despite awareness of potential sea level rise, the Port of San Diego is moving forward with a proposed half-billion dollar expansion of the San Diego Convention Center which may be flooded on a regular basis by tidal action (Sharma 2012; California Coastal Commission 2013b). This suggests the Port of San Diego is not yet taking seriously the posed by sea level rise, a supposition underscored by the Port Commission's 2013 decision to eliminate flood and earthquake insurance for the Convention Center (San Diego Convention Center 2014, 21).

[33] During development of the regional strategy planners realized they needed considerably more information to make informed choices about climate change adaptation. A research agenda was developed to pursue more information in the areas of sea level rise impacts, infrastructure vulnerability, to more accurately evaluate the potential impacts of climate change in San Diego Bay on infrastructure, ecosystems, and social groups (ICLEI 2013).

Table 5-2. Infrastructure vulnerability within Port of San Diego planning area
(Adapted from Hirschfeld and Holland 2012, 28-51)

Vulnerability	Climate Change Impact in 2050	Climate Change Impact in 2100	Primary Entity Responsible
Ecosystems and habitats	Inundation, habitat loss, erosion	Greater inundation, habitat loss, & erosion	Port of San Diego
Contaminated sites	Limited flooding and inundation	Flooding and inundation of many sites	Site owner/ manager
Storm sewer outfalls	Flooding and inundation	Flooding and inundation	Cities
Sanitary sewer	Flooding in low-lying areas	Inundation of underground system, flooding aboveground	Cities
Potable water	Limited flooding of above-ground components	Flooding and inundation of aboveground components	Cities, water authorities
Electrical transmission/distribution	Erosion of soil supporting surface components	Flooding and inundation of aboveground components	San Diego Gas & Electric
Local streets	Minimal flooding	Flooding and inundation	Cities
Commercial buildings	Limited flooding and inundation	Flooding and inundation of many buildings	Building owners
Parks, recreation, public shoreline access	Regular inundation and flooding of parks and recreational areas	Regular inundation and flooding of parks and recreational areas	Port of San Diego

5.3. Decision-Making for Climate Change Adaptation

5.3.1. Decision-Making Responsibility

Adaptation decision-making is complicated by the Port of San Diego's unique charter, which results in no entity controlling all aspects of adaptation planning for the Port of San Diego. The port itself is responsible for marine facilities (docks, piers, rails, etc., serving harbor), ecosystems, habitats, recreational areas, and public facilities falling within the planning area (see Figure 1.3 for approximate planning area boundaries). Of particular note, this responsibility extends to the San Diego Convention Center, the vulnerability of which to climate change has been previously discussed. The Port funds its activities, including capital improvements, from leases, rents, and service fees (Hooven 2015). Ultimate decisions on the capital improvement program are made by the Board of Port Commissioners. Although the Port of San Diego does not use tax revenue, the Board has the authority to levy taxes or issue bonds to fund improvements (UPSD 2008, 22). The Board of Port Commissioners may also exercise eminent domain within the boundaries of the port's planning area (Ibid., 9). However, the Port must amend its Master Plan and have it approved by the California Coastal Commission to implement protection measures in the coastal zone, or to use eminent domain for retreat measures (Herzog and Hecht 2013).

For all remaining infrastructure within the port's planning area, the Port of San Diego depends on others for adaptation decision, though port officials actively use their influence to advocate for adaptation to climate change (Hooven 2015). The port relies upon its member cities to review building permits for compliance with the city's specified building code (Hirschfeld and Holland 2012, 6), leaving decisions on building floor elevations to the member cities, too. Freshwater infrastructure is owned and maintained by the member cities as well as water authorities (Ibid., 40), whereas wastewater infrastructure is entirely controlled by the member cities (Ibid., 38). The same holds for local streets within the cities' respective limits (Ibid., 44). San Diego Gas and Electric owns and maintains natural gas infrastructure within the port's planning area, and they, too, are responsible for adaptation decisions pertaining to their infrastructure (Hirschfeld and Holland 2012, 42). In the absence of definitive guidance from the federal and state governments, each entity must decide on their own what the necessary level of adaptation will be.

5.3.2. Decision Support Tools for Climate Change

The Port of San Diego uses multi-criteria analysis (with embedded lifecycle analysis) for evaluation of proposed capital improvements (UPSD 2014). Port staff are considering using a new decision tool which more effectively considers the uncertainty inherent in climate change, though a new decision support tool has not yet been chosen (Hooven 2015). In lieu of an alternative process, port staff currently evaluate if a project is impacted by climate change *after* the project has been approved. If climate change might impact the project, port staff then determine what adaptation measures are necessary to enable the project to still go forward (Ibid.).

5.4. Climate Change Adaption Strategy

5.4.1. Plans and Policies Affecting Port Adaptation Strategy

No national strategy has been published for planning by ports for climate change resilience (Becker *et al* 2014), though such guidance is under development by the American Society of Civil Engineers Subcommittee on Sea-level Change Considerations for Marine Civil Works (Toilliez 2013). The National Environmental Policy Act and California Environmental Quality Act (CEQA) require consideration of climate change impacts on proposed projects, but comprehensive adaptation plans are not required by law (Messner *et al* 2013, 5). The Port of San Diego's 2012-2017 strategic plan for the port calls for sea level rise and climate change considerations to be incorporated long-range planning. (UPSD 2012b, 5). The current Port Master Plan does not reflect this intent, though the updated 50-year master plan, scheduled for release in 2017, is being updated to reflect the port's intent to "mainstream" adaptation into the port's regular business practices. (UPSD 2014).

As noted in section 5.3.1, the Port of San Diego shares adaptation responsibilities with its member cities: the adaptation plans of cities affect the port, and the plans of the port affect the cities. As a result the Port of San Diego joined with its member cities and the airport to publish the *Sea Level Rise Adaptation Strategy for San Diego Bay* in 2012. The report included a comprehensive vulnerability assessment, strategies for adaptation by sector, and suggested management practices for local governments and agencies. The strategy was compiled by ICLEI Local Governments for Sustainability USA under the auspices of a public agency steering committee, and stakeholder and technical working groups. Guiding principles of the strategy (adapted from Hirschfeld and Holland 2012, 3-4):

1. Adaptation planning and action must begin now.
2. Use best available science to identify climate change risks and adaptation strategies.
3. Utilize a “living,” flexible adaptation strategy designed to adjust to improved understanding of climate change as well as unexpected climate changes.
4. Involve stakeholders, including governments, tribes, citizens, businesses, landowners, and non-governmental organizations, at all stages of adaptation strategy development.
5. Reduce risk to coastal communities by using a precautionary approach.
6. Prioritize strategies which continue existing governmental initiatives for the benefit of society, the environment, and greenhouse gas mitigation without requiring additional funding or personnel.
7. Protect public health, safety, critical infrastructure, ecosystems, parks, and recreational areas.
8. Plan for long-term sustainability of new development, and to reduce vulnerability of existing development over time.

Other federal and state plans and policies in various stages of development and publication may influence adaptation policy at the Port of San Diego, and are discussed in the following sections. Since the Port of San Diego's adaptation strategy is not yet finished, the degree to which it is influenced by federal and state policy remains to be determined.

5.4.1.1. Federal Law and Policy

Several initiatives are underway at the federal level which have the potential to affect adaptation planning for port infrastructure. Among these is the 13-agency U.S. Global Change Research Program, which works to improve understanding of climate change impacts in the United States as well as support for decision-makers making adaptation decisions (Executive Office 2013). A second initiative is the National Institute of Standards and Technology's Disaster Resilience Framework and Disaster Resilience Standards, both of which will have considerable implications for adaptation by American ports (NIST 2014).

Given the threat posed by storm surge (an extreme event) to ports, this guidance will clearly influence port adaptation planning. The 50% draft of the Framework calls for community (including ports) resilience planning to prepare for routine, expected, and extreme events (Ibid., 29).

- Routine events occur frequently and are below the building design load. Systems should remain fully functional without significant damage.
- Expected events correspond to the design hazard level of the system or building. Systems should remain sufficiently functional to support disaster response and recovery.

- Extreme events are the maximum considered based on historic events as well as changes resulting from climate change. Critical systems must continue to function. Other systems and buildings need only protect residents and allow them to evacuate on their own. Emergency plans are based on these events.

The design loads specified by the American Society of Civil Engineers[34] and summarized by NIST (2014, 30) in the draft framework, as shown in Table 5-3. The original table has been truncated to only include the most common risks to port infrastructure from climate-change related events.

Table 5-3. Design loads for buildings and facilities
(Adapted from NIST 2014, 7)

Hazard	Routine	Expected	Extreme
Rain	As specified by local code		
Wind - Extratropical	50 year	700 year	3,000 year
Wind – Hurricane	50-100 year	700 year	3,000 year
Tsunami	50 year	500 year	2,500 year
Flood	100 year	100-500 year	TBD

Critical facilities must remain functional or be restored to 90% of functionality within 3 days of an event (NIST 2014). The ASCE 24-05 Flood Resistant Design and Construction standard considers the following structures (when built in a floodplain, as most ports are), to be essential:

- Healthcare facilities which provide emergency treatment.
- Fire, rescue, ambulance, and police stations and emergency vehicle garages.
- Emergency shelters.
- Emergency operations centers and facilities supporting emergency response.

[34] Officially, Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10).

- Power generating stations and other public utility facilities required in an emergency.
- Ancillary structures, such as communication towers, fuel storage tanks, cooling towers, electrical substation structures, water storage facilities for fire suppression, etc., which support essential functions.
- Air traffic control centers.
- Buildings and other structures of military importance.

5.4.1.2. State of California Law and Policy

In general, California state law restricts diking, filling, or dredging within tidelands at a port unless doing so is in accordance with a Port Master Plan certified by the California Coastal Commission for compliance with California's Coastal Act (Herzog and Hecht 2009, 58-61). Herzog and Hecht (2009, 61) conclude the California Coastal Commission would only be inclined to support "protection" (e.g., coastal armoring) at the very lowest cost to the environment. In addition, the Port of San Diego must consider the effects on recreational areas, public access, the environment, and commercial businesses of any proposed adaptation action. Although it would not be a popular choice, as a last resort the port may utilize eminent domain to facilitate planned withdrawal to higher inland elevations, though this is unlikely due to the high political and financial costs involved (Herzog and Hecht 2009, 61). Furthermore, use of eminent domain may impact historic properties, which may incur an entirely different set of administrative problems (Phelps 2014).

In the absence of binding regulations for climate change adaptation, the State of California has been proactive in prompting coastal communities and organizations plan to adapt. California

State Executive Order S-13-08 required state agencies (including the Port of San Diego) to plan for sea level rise and climate change. The California Natural Resources Agency followed up with the 2009 California Climate Adaptation Strategy, whose guiding principles were largely adopted by the *Sea Level Rise Adaptation Strategy for San Diego Bay* (adapted from California Natural Resources Agency 2009, 5):

- Use best available science to identify climate change risks and adaptation strategies.
- Utilize a “living” adaptation strategy designed to adjust to unpredictable climate changes.
- Involve stakeholders, including governments, tribes, citizens, businesses, landowners, and non-governmental organizations, at all stages of adaptation strategy development.
- Prioritize strategies which continue existing governmental initiatives for the benefit of society, the environment, and greenhouse gas mitigation without requiring additional funding or personnel.

Further recommendations are provided by the State of California’s Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), who released an updated guidance document in 2013. Key recommendations (State of California 2013, 2-6):

- State agencies should appropriate discretion for planning with respect to infrastructure adaptive capacity, impacts resulting from decisions, and the agency’s risk tolerance.
- Coordinate with other agencies in the region to use the same sea level rise projections.
- Consider local sea level trends, but do not use them as the basis for a linear extrapolation of future sea levels.

The final regulation of note is the California Coastal Commission Sea-Level Rise Policy Guidance, still in draft form as of February 2015. Once formally approved this document will be binding upon any development within the Port of San Diego's planning area.

5.4.2. Process to Develop Adaptation Strategy

The port is working on a 50-year comprehensive plan (to be completed 2017) which will update the Port's Master Plan (UPSD 2014b). At the same time, the port is developing a climate adaptation strategy to complement the Port's Climate Action Plan for reduction of greenhouse gases, though it is uncertainty if the adaptation strategy will also be complete in 2017 (Hooven 2015). Development of the in-progress Port of San Diego Climate Adaption Plan is generally following the process (see Figure 5.1) developed by the ICLEI-Local Government for Sustainability[35] (adapted from Cody *et al* 2011):

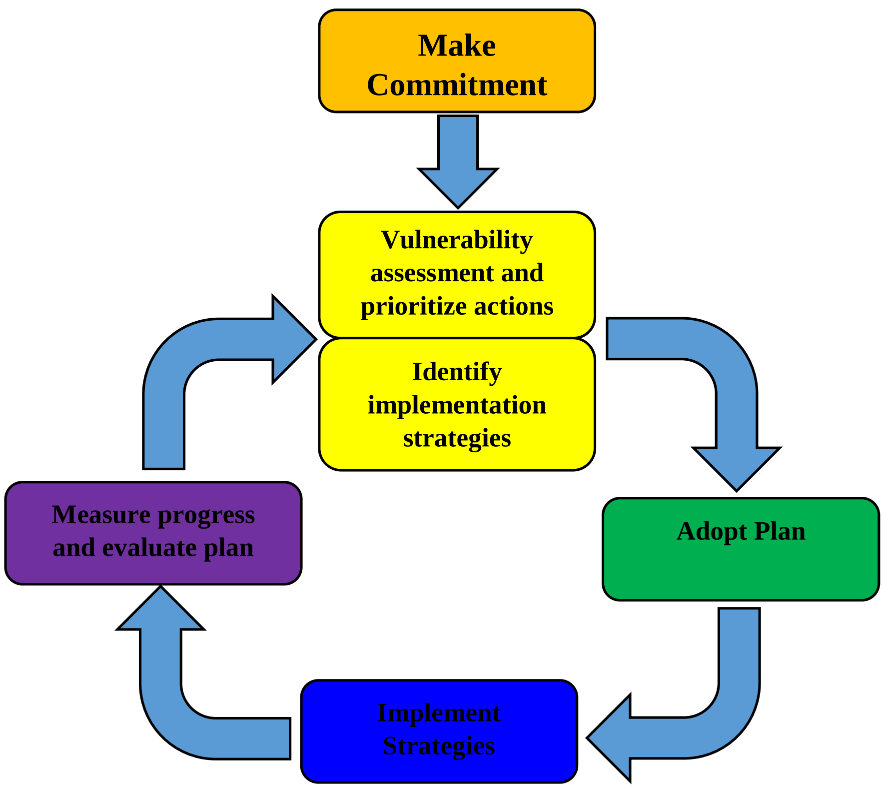
1. Document existing conditions using a geographic information system (GIS). Data collection methods included:
    - Shoreline elevations
    - Light Detection and Ranging (LIDAR)
    - Land use designations
    - Bathymetry
    - Infrastructure and natural resource mapping
2. Complete vulnerability assessment based on port infrastructure and functions at risk based on 2050 and 2100 climate scenarios. Inundation areas based on the chosen climate

[35] ICLEI-Local Government for Sustainability is a component of ICLEI USA, an "association of cities and counties committed to climate action, clean energy, and sustainability" (ICLEI 2015).

scenarios were identified, then compared to land use, environmental value, and other chosen attributes to evaluate potential climate impacts.

3. Prioritize adaptation actions to address key vulnerabilities. Evaluation is based on risk metric (still under development) which ranks likelihood against consequence on a scale of one to five. Composite risk is determined, thus identifying priority areas for adaptation measures.
4. Develop implementation strategies.

Figure 5.1. Process for climate adaptation planning for Port of San Diego
(Adapted from Hooven 2013, 11)



While developing their adaptation strategy Port of San Diego staff identified a need for a sophisticated hydrodynamic model for San Diego Bay to more accurately model sea level rise, wave run-up and storm impacts, enabling more accurate identification of infrastructure risk and vulnerability (UPSD 2014b). The Port applied for a grant to conduct the study which pushed back finalization of the port's adaptation strategy until at least 2017 (UPSD 2014).

5.4.3. Adaptation Strategy

The Port of San Diego does not have a formal adaptation strategy. In the absence of such, an examination of supporting documents suggests the Port will largely rely upon a strategy of accommodation based on soft adaptation measures (Hirschfeld and Holland 2012; UPSD 2012a). The Chula Vista Bayfront Master Plan, which will govern development of Chula Vista's waterfront, includes policies specifying accommodation in areas are vulnerable to sea level rise (UPSD 2012a, 4-5). The port does not intend to relocate further inland due to the prohibitive cost as well as non-alignment with its organizational mission (UPDSD 2014).

5.4.4. Stakeholder Engagement on Adaptation Strategy

The Port of San Diego clearly recognizes interjurisdictional collaboration is required (Hooven 2013; UPSD 2013), otherwise the necessary level of adaptation at the port will not occur. The complete list of organizations with jurisdiction within San Diego Bay includes: San Diego Unified Port District; Cities of San Diego, Imperial Beach, Chula Vista, and Coronado; San Diego Regional Airport Authority; California Coastal Commission; U.S. Navy; U.S. Fish and Wildlife Service; and the California Department of Parks and Recreation (Hirschfeld and

Holland 2012, 6-7). Each entity provided representatives on the stakeholder working group which developed the *Sea Level Rise Adaptation Strategy for San Diego Bay*.

Given the diverse membership, it is not surprising the 2012 *Sea Level Rise Adaptation Strategy for San Diego Bay* was a collaborative effort amongst stakeholders. Using a workshop format, public and private stakeholders, scientists, and representatives from ICLEI-Local Governments for Sustainability developed common assumptions and recommendations which all supported (Hirschfeld and Holland 2012, iii). The strategy will be updated as necessary as more information becomes available regarding sea level rise and strategies for adapting to it (Ibid.).

The Port also plays a leading role in the San Diego Climate Collaborative, a voluntary organization which allows public agencies in the San Diego region to partner with scientists, businesses, and non-governmental organizations to "share expertise, leverage resources, and advance comprehensive solutions to facilitate climate change planning" (San Diego Climate Collaborative 2015). The Collaborative does not include any federal or state agencies which are responsible for portions of the San Diego Bay, a shortfall given that the State of California and the U.S. Military also control large sections of the tidelands and shoreline.

5.5. Adaptation Actions

5.5.1. Adaptation Actions

In the absence of an official adaptation strategy from the Port of San Diego, suggestions of the adaptation decisions to be made for the Port of San Diego are provided by the *Sea Level Rise Adaptation Strategy for San Diego Bay* as well as the adaptation plans of the cities adjoining San

Diego Bay. Nearly all actions in the strategy are “soft,” no-/low-regret, flexible or reversible, and have synergy with other priorities, the characteristics of robust adaptation named by Hallegatte (2009). Although intended for region-wide implementation, the recommended actions are pertinent to the Port of San Diego (adapted from Hirschfeld and Holland 2012, 22-26):

1. Establish a regional, staff-level sea level rise working group, composed of personnel from public agencies around San Diego, to put Adaptation Strategy into practice.
2. Establish recurring stakeholder meetings in support of the Adaptation Strategy.
3. Improve outreach and education for government staff and city residents regarding sea level rise, climate change, and the need to implement the Adaptation Strategy.
4. Pursue research on vulnerabilities, potential impacts from sea level rise, and possible adaption measures for San Diego-area organizations.
5. Pursue unequivocal guidance from state and federal governments on how to address the potential impact of sea level rise on new development.
6. Pursue new floodplain maps showing potential sea level rise from the Federal Emergency Management Agency (FEMA).
7. Incorporate adaptation to sea level rise into the Port of San Diego Master Plan, the Port’s regular business practices, and other Port plans and programs.
8. Follow the sea level rise guidance from the State of California Climate Action Team (discussed in section 5.2.1).
9. Conduct site-specific vulnerability assessments for important plans and projects.
10. Establish a decision-making process for choosing adaptation actions.

According to the City of Chula Vista's *Climate Adaptation Strategy* (2011, 36-37), the city is pursuing three immediate actions for "tidally influenced" areas:

1. Update city ordinance for building ground floor elevations to plan for 18" of sea level rise over the next 50 years. Update the ordinance every five years as additional information becomes available.
2. Update city Subdivision Manual to ensure storm drainage systems in new developments are designed for 18" of sea level rise and a 100-year storm occurring at highest high tide.
3. Update city environmental review procedures to ensure compliance with CEQA for any project which may impact environmental quality as sea levels rise.

Chula Vista's Bayfront Master Plan (2012) also specifies specific adaptation actions, including limiting development within the 2050 and 2100 floodplains and establishing upland ecosystem buffer zones to support habitat migration in conjunction with sea level rise.

National City has published a *Climate Action Plan* (2011) to reduce greenhouse gas emissions. The city also established goals in its General Plan to create adaptive management policies to adapt to rising sea levels, reduced water supplies, and other effects of climate change (National City 2011, 3-204). As of January 2015 no formal political movement on a sea level rise adaptation strategy had occurred (Pe 2015).

The City of San Diego intends to develop a climate adaptation plan, though the city acknowledges its incomplete understanding of climate risks and vulnerabilities of the city's infrastructure (including city streets and utilities within the Port of San Diego's planning area)

(City of San Diego 2014, 64). At this time the city is requesting funding from state and federal sources to develop a complete adaptation strategy.

The City of Coronado has not published a climate change adaptation strategy nor a list of adaptation actions. The city's Local Coastal Land Use Program, last updated in 2005, makes no mention of climate change or sea level rise, though city staff anticipate Coronado will eventually adopt a long-term plan (which will need to consider sea level rise) for facility replacement (Maurer 2015).

The City of Imperial Beach was awarded a grant in January 2014 to complete a vulnerability assessment and develop an adaptation strategy for adapting to sea level rise (Imperial Beach 2015). This strategy will be complete in January 2016. Otherwise, no formal action has occurred.

5.5.2. Supporting Data for Decisions

Floodplain modeling, based on the sea level rise predictions provided by the State of California (see section 5.2.1., Table 2-1), was conducted to identify systems and functions around San Diego Bay at risk from climate change. The same level of analytical rigor is not apparent in the discussion of the adaptation actions listed in the previous section. Instead, the actions are largely based upon perceived adaptation best management practices as well as stakeholder and expert opinions (Hirschfeld and Holland 2012; Hooven 2015). To be fair, many "soft" adaptation actions do not require in-depth analysis to merit their selection, though one should expect defensible, data-driven rationale for long-life infrastructure affected by climate change. A case in point is the proposed $520 million expansion of the convention center, which may be substantially impacted by climate-change related events.

5.5.3. Incorporation of Adaptation Actions into Capital Improvement Plan

The Port of San Diego uses a standard five-year capital improvement planning program (UPSD 2014). Although projects may be initiated by nearly anyone, including Port staff and commissioners, member cities, and members of the public, all projects undergo a multi-criteria analysis by Port staff. Projects are ranked and funded in order of priority. At this time no adaptation-specific projects have been included in the Port of San Diego's 5-year CIP (Hooven 2015).

5.6. Adaptation Finance

Funding for adaptation within the Port of San Diego's planning area is tied to decision-making responsibility (discussed in section 5.3.1, Table 5-2). The Port of San Diego is responsible for paying for adaptation of public, recreational, and maritime facilities with income from leases and service fees. The Port also has the authority to levy taxes and issue bonds for climate change adaptation projects (UPSD 2008), though it is unknown if the Port would make use of this authority for that purpose. Port staff also stated they would pursue all applicable federal and state funding to finance necessary adaptation measures (Hooven 2015). Although a prospective tenant normally pays for development on Port land, it has not been determined if this policy will apply to necessary climate change adaptation measures (Hooven 2015). Financing adaptation of all other infrastructure, including utilities and local streets, is the responsibility of the infrastructure owner. Although the Port of San Diego has not chosen a financing method for climate change adaptation, multiple avenues are available, providing port officials with a robust set of options.

5.7. Adaptation Timeline

Unlike the Port of Rotterdam, the Port of San Diego does not have a politically motivated goal for achieving a certain level of climate change adaptation (Van Barneveld 2014), though the port is required by California to complete an adaptation plan by 2019 (Hooven 2015). Port planners they expect to follow the recommendation of the California Coastal Commission and use a planning horizon of 2100 (Hooven 2015).

5.8. Status Report: Implementing Adaptation Plans

Sea level rise is a threat to the Port of San Diego and neighboring communities in 2050 and 2100 (Hirschfeld and Holland 2012; Messner *et al* 2013). Despite the potential damage which might result from sea level rise, adaptation planning has proceeded slowly in the wake of the 2012 *Sea Level Rise Strategy for San Diego Bay*. Even so, progress has been made towards achieving some of the objectives in the plan pertinent to the Port. The San Diego Climate Collaborative (SDCC) was established as a forum for regional stakeholders to share best practices and resources. A representative from the Port chairs the SDCC Steering Committee. In cooperation with the airport authority, the Port of San Diego commissioned a detailed hydrodynamic model of the impacts of future sea level rise and wave action in San Diego Bay. Once completed the model will support completion of the Port’s vulnerability assessment and adaptation plan.

Although the Port of San Diego has taken positive steps towards development of an adaptation plan, a comprehensive document is years away. The Port did collaborate on the Chula Vista Bayfront Strategy, which incorporated minor policies for adapting to sea level rise, but that document is only suggestive of the adaptation choices which the Port will eventually make. Otherwise, the Port is not completing any capital improvement projects at this time which will be affected by climate change (Hooven 2015).

5.9. Summary of Adaptation Planning Choices

The Port of San Diego has made few of the key adaptation choices studied by this project. In the interim port officials are making decisions on major infrastructure which may be highly vulnerable to future climate change. Table 5-4 summarizes the adaptation choices recommended by the regional *Sea Level Rise Strategy* for *San Diego Bay* and the adaptation choices made by the Port of San Diego itself, or by entities responsible for infrastructure within the Port's assigned planning area.

Table 5-4. Summary of Adaptation Choices for the Port of San Diego

Adaptation Choice to be Made	San Diego Bay Sea Level Rise Strategy Recommendations	Port of San Diego Adaptation Choices
Climate Scenario	2050: 0.5 m (20”) sea level rise + 100-year extreme event 2100: 1.5 m (59”) sea level rise + 100-year extreme event	2050: 0.5 m (20”) sea level rise + 100-year extreme event 2100: 1.5 m (59”) sea level rise + 100-year extreme event
Decision Support Tool	None chosen	None chosen by Port for adaptation. Use multi-criteria analysis with embedded lifecycle analysis for CIP.
Strategy	Accommodation based on a precautionary approach.	Accommodation, no large-scale withdrawal (stated preferences).
Actions	*“Hard” accommodation:* 1. Incorporate sea level rise into required base floor elevations for new development. *“Soft” accommodation:* 1. Increase interagency coordination 2. Improve planning capability 3. Conduct vulnerability assessment 4. Conduct site-specific assessment for important projects 5. Mainstream adaptation planning into organizational business practices 6. Establish decision-making process	None explicitly chosen by Port. Small-scale withdrawal (upland buffers) and accommodation (higher base floor elevations) in Chula Vista.
Financing	Pursue adaptation-related funding.	Port revenue (leases, fees, bonds, taxes), city governments, and utilities.
Planning Timeline	2100	2100 (stated preference)

6. Adaptation Planning for Naval Base Kitsap – Bremerton

6.1. Introduction

As explained in section 1.7.3, the U.S. Navy is solely responsible for climate change adaptation planning at Naval Base Kitsap – Bremerton (NBK). Since Department of Defense and Department of the Navy adaptation policies have not been published, Naval Facilities Engineering Command (NAVFAC) has not moved forward with local adaptation planning at NBK. The City of Bremerton, which embraces NBK on three sides, has not begun planning for climate change, either (Floyd 2015). Consequently, this chapter is considerably shorter than those for the Ports of Rotterdam and San Diego. To the extent possible indications of future adaptation decisions are discussed to illustrate the current direction of Navy adaptation thought and planning.

The current direction of Navy adaptation efforts, paired with the lessons learned from the Port of Rotterdam and Port of San Diego, will inform development of an adaptation planning framework for U.S. Navy ports in Chapter 7.

6.2. Choosing a Climate Change Scenario

6.2.1. Climate Change Scenarios

In lieu of climate change scenarios which have not been developed for NBK, one may construct a simple climate scenarios for the Puget Sound area using regional data. Over the period of 1895-2011 average temperature in the Pacific Northwest increased by 1.3°F (Kunkel *et al* 2013). Looking to 2100, the average annual temperature in the region is expected to increase by 3.3°F to 9.7°F, with the most severe increases occurring during summertime (Ibid.). Seasonal precipitation is expected to change also, though models disagree whether average seasonal precipitation will increase or decrease (Ibid.). However, most models agree summer precipitation will increase overall (Kunkel *et al* 2013; Mote and Salathé 2010). In addition, regional snowmelt patterns are expected to change, reducing water supply during the summer months to parts of the Northwest (Mote *et al* 2014).

Over the period 1906-2008 sea level rise in the City of Seattle, not far from NBK, averaged 2.01 mm/year (NRC 2012, 95). Looking forward, two sets of regional sea level rise projections have been published (see Table 6-1) for the Puget Sound area for the year 2100. The projections are not directly comparable due to differing constructions of the models and underlying assumptions, though the models predict similar results. It is important to note that to achieve the high-end sea level rise projection the rate of sea level rise would need to accelerate to 3-4 times the current rate (NRC 2012). Although rates are expected to accelerate in the coming decades as the pace of global warming quickens, net sea level rise in 2100 is highly uncertain (Reeder *et al* 2013).

Table 6-1. Sea level rise projections for 2100 for the Puget Sound region

Scenario	Mote *et al* (2008)	NRC (2012)
Low	16 cm (6.3”)	10 cm (3.9”)
Medium	34 cm (13.4”)	62 cm (24.4”)
High	128 cm (50.4”)	143 cm (56.3”)

6.2.2. Naval Base Kitsap – Bremerton Infrastructure At Risk Due to Climate Change

A general assessment of Navy infrastructure at risk from climate change was completed by Naval Facilities Engineering Service Center in 2009. The report identified early snow melt, air quality degradation, urban heat island, wildfire, heat waves, drought, tropical storms, extreme rainfall (and flooding), and sea level rise as potential climate impacts to the Pacific region (Alaska, California, Oregon, Washington, and Hawaii). In general, this may result in many of the impacts noted in Table 2-2 in section 2.3, such as inundation, flooding, erosion, and other forms of infrastructure damage.

A report on potential sea level rise impacts to NBK found that the dry docks are approximately 1 meter above the record high tide for Seattle, and about 1.65 meters above mean high water (Knott 2007). Under the low and medium sea level rise scenarios shipyard facilities are projected to remain dry, but under the high sea level rise scenarios regular inundation would occur in the year 2100 (Ibid.). Floodplain maps of NBK are not maintained, precluding evaluation of current flood and storm surge risk to shipyard facilities. Several projects have been initiated recently, though, to address increasingly higher high tides which have caused flooding of dry dock service galleys (Collier 2015).

6.3. Decision-Making for Climate Change Adaptation

6.3.1. Decision-Making Responsibility

NAVFAC is responsible for planning, building, and sustaining the U.S. Navy's infrastructure as well as environmental management, base operating services, and environmental management (NAVFAC 2008, 1-1). Logically, then, NAVFAC also retains lead responsibility for planning for climate change adaptation at U.S. Navy bases, including Naval Base Kitsap – Bremerton. Puget Sound Naval Shipyard (PSNS), an important tenant command on Naval Base Kitsap, maintains an internal facilities staff to plan and manage the shipyard's assets. NAVFAC PWD Kitsap staff expect to collaborate with PSNS facilities staff on local climate change adaptation planning.

Staff from Naval Base Kitsap, the shipyard "owner," would also participate but not lead the adaptation planning process.

6.3.2. Decision Support Tools for Climate Change

A new decision support tool based on risk-management is under development for Navy climate change adaptation decision-making, but its final form has not been decided (Marburger 2015).[36] At present NAVFAC relies on net present value life-cycle cost analysis as the primary decision support tool for project approvals (DON 2014a). Although the process is also influenced by more subjective considerations, such as "impact on missions and personnel," standard NAVFAC policy is for construction, operation, maintenance and repair of Navy facilities to be completed by the most "economic and fiscally sound means possible" (Ibid., 1-1). This process could be adapted to include robustness criteria, as suggested by Hallegatte (2009) and Whittington and Young (2014).

PSNS facilities are planned with a 67-year service life but are depreciated to terminal value after 32 years (Goalby 2015). As a result, when completing a life-cycle cost analysis with a fixed discount rate, benefits or costs occurring after the 32nd year have minimal influence on net present value life-cycle cost calculations, despite the use of the facility for many years afterward. This leads to decisions which are strongly influenced by benefits and costs early in the facility life-cycle, neglecting long-term costs and benefits due to climate change events after the 32-year

[36] An in-development version of the DOD adaptation policy proposes a three-dimensional risk management tool to support adaptation choices (Marburger 2015). The tool will assist planners to evaluate climate risks to Navy infrastructure, climate risks to naval functions, and length of time exposed to climate risks (e.g., "time-risk," which accounts for the uncertainties of climate change which increase over time). This tool would be adaptable to local climate conditions, including measured and projected sea level rise, for use by planners at each military installation.

mark. The Dutch government is wrestling with the same problem (see section 4.3.2), and appears inclined to use a cost-benefit analysis with a declining discount rate, more fully capturing long-term benefits and costs of a given adaptation measure (Ministry of Infrastructure 2014).

6.4. Climate Change Adaption Strategy

6.4.1. Plans and Policies Affecting Shipyard Adaptation Strategy

6.4.1.1. National Adaptation Policy

Executive Order (EO) 13653 "Preparing the United States for the Impacts of Climate Change" was issued in November 2013 as a follow-up to *The President's Climate Action Plan*. EO 13653 recognized climate change is already occurring and required federal agencies to improve their climate change preparations through information-sharing, "risk-informed decision-making," continuous learning throughout the adaptation process, and resilience planning. Among the more specific requirements the order requires the federal government to "reform policies and Federal funding programs that may, perhaps unintentionally*, increase the vulnerability of natural or built systems* [italics added], economic sectors, natural resources, or communities to climate change related risks."

Prior to release of EO 13653, federal agencies prepared comprehensive Agency Adaptation Plans in response to EO 13514, *Federal Leadership in Environmental, Energy, and Economic Performance* (2009). Within the adaptation plans agencies evaluated short and long-term risks climate change represented to their operations and detailed actions the agencies would take to mitigate these risks. EO 13653 requires agencies to continue building, refining, and implementing their comprehensive adaptation plans to ensure climate change considerations are incorporated into all aspects of agency operations. Federal agencies are required to report annually on progress towards achieving climate change resiliency.

The White House added to above the guidance by issuing Executive Order 13690 "Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input" in January 2015. Among other requirements, the order required federally-funded projects to avoid construction in 100-year floodplains. Non-critical activities are to be elevated 2 feet above the 100-year floodplain, and critical activities are to be elevated 3 feet above the floodplain.

The 2008 National Defense Authorization Act required DOD to evaluate the impact of climate change on military bases, functions, and assigned tasks. Since that time, the U.S. Congress has not enacted legislation specifying a required level of climate change adaptation by ports or the U.S. military.

6.4.1.2. Department of Defense Adaptation Policy

Beginning with the 2010 Quadrennial Defense Review (QDR),[37] the DOD officially recognized the need to adapt to climate change-related impacts on facilities and infrastructure. Official DOD policy is to sustain military readiness despite climate change (DOD 2012a), committing the military to climate change adaptation; to refuse to adapt is to risk the inability to fulfill the DOD's mandate. To do so the DOD has indicated an interest in "robust risk management processes that account for dynamic factors" (DOD 2014a, 11), although no formal direction has

[37] The QDR establishes strategic national security policies and long-term initiatives.

been given regarding use of robust decision-making methodology. DOD uses RDM in this context in reference to robust adaptation choices (Hallegatte 2009) based on broadly supported climate scenarios, rather than the full RDM process of statistical climate scenario development (Kalra *et al* 2014; Lempert, Popper, and Bankes 2003). Additionally, the DOD intends to incorporate consideration of climate change, based on "best-available science," into existing management processes rather than establish a stand-alone framework for mitigation and adaptation (DOD 2012a, 7).

The Unified Facilities Criteria (UFC) for Installation Master Planning, among many other planning requirements, directed military planners to consider *projected* climatic changes during the design life of facilities and military base infrastructure (DOD 2012c). Projections are to be based on work by "reliable and authorized sources (e.g., Census Bureau for population projections, U.S. Geological Survey for land use change projections, and U.S. Global Change Research Office and National Climate Assessment for climate projections)." Which climate scenarios should be used, nor acceptable levels of risks for functions or systems, are not specified. Given the wide range of potential global sea level rise in 2100 (see section 2.2.2), as well as the fact that regional sea level rise will vary considerably (SERDP 2013), such guidance is not sufficient for planning purposes.

The UFC for High Performance and Sustainable Building Requirements also requires installation planners to consider projected climate changes during building design life (DOD 2014d). For life-cycle cost analysis the default building life is limited to no more than 40 years, although the military services are given leeway to use different service lives. It is common knowledge amongst Navy planners that many Navy buildings are more than 70 years old, thus suggesting base floor elevations and design loads should be based on potential future climate conditions over the building's full design life.

In February 2014 the DOD restricted construction within the 100-year floodplain to projects which military necessity requires to be built within the floodplain (i.e., piers and wharves) (Conger 2014). Flood mitigation measures are required of new projects and renovation projects of more than $7.5 million located within the floodplain. At a minimum mechanical and electrical subsystems are to be protected against flood risk. This restriction will be tightened further based on the January 30, 2015 release of Executive Order 13690, which required non-critical activities to be elevated at least two feet above the 100-year floodplain, and critical activities, at least three feet (White House 2015).

Most recently the DOD released the 2014 Climate Change Adaptation Roadmap. The roadmap calls for DOD to identify, evaluate, and address climate change impacts and risks to DOD operations, including impacts to facilities and installation management. Throughout the adaptation process DOD will engage with agencies and governments outside the DOD in order to most effectively adapt to the risks of climate change. In the process, the military services are to review and modify as needed the following plans and guidance (DOD 2014a, 10):

- Installation Master Plans to guide development activities.
- Integrated Natural Resource Management Plans, Integrated Cultural Resource Management Plans, and Integrated Pest Management Plans.
- Design and construction standards.

- Encroachment management plans and other utility systems.
- Facility maintenance and repair cost models.
- Installation-level water resource management plans.
- Emergency preparedness and response training.

6.4.1.3. Navy Adaptation Policy

In response to Executive Order 13514 the Navy established Task Force Climate Change in 2009 and released the U.S. Navy Climate Change Roadmap in 2010. The ultimate purpose of the roadmap is to ensure (DON 2010):

- All Navy missions can be accomplished despite any climate changes which may occur over the next 30 years.
- The Navy understands "timing, severity, and impact" of global climate change projections.

Although Task Force Climate Change has been active since its inception in 2009, adaptation Navy-wide guidance on adaptation has not been published. Furthermore, as of February 2015, Naval Facilities Engineering Command (NAVFAC) does not have a comprehensive policy for adaptation to climate change.[38] Climate change is not mentioned in the 2013-2016 NAVFAC Strategic Plan, nor is adaptation to its effects. A scan of the official missions, functions, and tasks of NAVFAC also does not mention adaptation to climate change (U.S. Navy 2012).

[38] Whereas the U.S. Army Corps of Engineers has had a climate change adaptation policy since 2011, directing the integration ("mainstreaming") of "adaptation planning and actions into [the Corps'] missions, operations, programs, and projects." For example, as noted in section 2.2.2, USACE requires use of a sea level rise calculator to produce low, medium, and high range projections of sea level rise in 2100.

Even though the Unified Facilities Criteria discussed above apply equally to all military services, NAVFAC has not provided guidance for effective implementation of these criteria. Finally, conversations with decision-makers reveal that while NAVFAC officials are aware of the policy gap regarding climate change adaptation, they are waiting for guidance from the DOD and Navy, which may not be forthcoming for a year or more.

6.4.2. Process to Develop Adaptation Strategy

Since NAVFAC guidance for climate change adaptation has not been written, the desired process for developing local adaptation plans is unknown. However, it is reasonable to expect that after adaptation objectives and priorities for a given Navy installation are publicly identified, the steps necessary to achieve the objectives will be "mainstreamed" into NAVFAC's existing business practices. Facility energy efficiency considerations were integrated in a similar manner, and it stands to reason the same approach will be applied to climate change adaptation planning. After the initial publicity surrounding the adaptation strategy, "resilience to climate change" would become another design criterion to be met, along with wind loads, environmental regulations, building codes, among others.

6.4.3. Adaptation Strategy

An adaptation strategy for Naval Base Kitsap – Bremerton has not been developed, nor has planning been initiated to develop a strategy.

6.4.4. Stakeholder Engagement on Adaptation Strategy

No Navy guidance exists to assist NAVFAC PWD Kitsap with stakeholder engagement for adaptation strategy development. However, in January 2015 NAVFAC Headquarters contracted with a communications firm for development of a climate change communication strategy for individual Navy bases when engaging with stakeholders both on-base and off (Venable 2015; Walker 2015). Furthermore, established processes are available for NAVFAC employees to follow when engaging with on-base customers (such as PSNS), or when conducting joint land use studies with surrounding communities. If a regional climate change adaptation strategy was desired, the Navy could expand the existing joint land use study, which focuses on zoning and traffic management, with the City of Bremerton to investigate the issue. This has not occurred for PSNS, which stands in direct contrast to San Diego, where the U.S. Navy actively participated in development of the *San Diego Bay Sea Level Rise Adaptation Strategy*.

6.5. Adaptation Actions

6.5.1. Adaptation Actions

The 2009 report from Naval Facilities Engineering Service Center recommended the following adaptation actions be considered “high-priority,” though they have not been adopted into a formal adaptation policy:

1. Assessment of climate change impact on key bases, infrastructure, and facilities.
2. Create process to incorporate adaptive design into new construction.
3. Retrofit or waterproof critical infrastructure (e.g., underground utilities).
4. Fortify shoreline against erosion during extreme events.
5. Create inundation models to evaluate vulnerability of facilities and functions.

6. Retrofit or relocate critical facilities.

As noted in section 6.2.2, flooding due to higher high tides has prompted projects to raise some dry dock service gallery walls. These projects are ad hoc, “hard” protective measures implemented in the absence of an adaptation strategy. No other adaptation projects have been planned or executed.

6.5.2. Incorporation of Adaptation Actions into Integrated Priority Lists

NAVFAC PWD Kitsap completes long-range facility planning for PSNS as well as facility construction, maintenance, and management (NAVFAC 2008). PSNS facilities staff work with PWD Kitsap staff to produce the long-range plans. PWD Kitsap develops a list of military construction (MILCON) capital projects,[39] which are then incorporated into NBK’s Integrated Priority List (IPL), the Navy’s version of a capital improvement plan. Decisions on project prioritization and funding are made by regional and national NAVFAC headquarters (Ibid.). It is anticipated the forthcoming Navy and NAVFAC adaptation guidance will direct how climate change adaptation-related projects should be incorporated into IPLs.

6.6. Adaptation Finance

Facility construction and land use and infrastructure planning are funded by NAVFAC via congressional appropriation. Organizations which occupy NAVFAC-managed facilities, such as PSNS, reimburse NAVFAC for facility management and maintenance and utilities consumed. These payments are made through the Navy Working Capital Fund (NWCF), an annual revolving fund that finances the provision of goods and services on a reimbursable basis (Ibid.).

[39] MILCON projects are new construction of $750,000 or more.

No funding sources have been identified for climate change adaptation at Navy installations, nor has any indication been given as to how adaptation may be funded. Generally, two options are available: 1) the U.S. Congress establishes a separate type of infrastructure funding for climate change adaptation; 2) or the U.S. Congress does *not* establish a separate type of funding for climate change adaptation, but instead requires the DOD to prepare for climate change using existing funding streams.

6.7. Status Report: Implementing Adaptation Plans

Although the work is not yet finished, the DOD and Navy have been working for most of the last decade to craft a climate change adaptation process for individual Navy installations to implement. A screening survey was conducted in 2014 to identify Navy facilities within two kilometers of a coastline that would be vulnerable to sea level rise, storm surge, extreme temperatures, and other aspects of climate change (OUSD 2014). It is expected these survey results will inform the detailed DOD adaptation policy currently under development.

Release of the DOD policy will be followed by Navy and NAVFAC policies, which in time will lead to development of a local adaptation strategy for Naval Base Kitsap – Bremerton by NAVFAC Public Works Department Kitsap and PSNS facilities staff.

6.8. Summary of Adaptation Planning Choices

Climate change, and sea level rise in particular, is believed to pose a minimal threat to Naval Base Kitsap – Bremerton for many decades, thus precluding any attempt at adaptation planning

(Collier 2015; Goalby 2015). Although assuming climate change to be a non-threat may be a tenuous assumption, it is very likely no adaptation planning will occur until definitive adaptation guidance is provided by NAVFAC for shipyard planners to follow. As a result, the general adaptation planning framework outlined in Chapter 7 is largely based on the decisions made by the Port of Rotterdam and the Port of San Diego, and is only minimally influenced by the current direction of adaptation thinking of U.S. Navy officials.

7. Analysis of Adaptation Choices from a Robustness Perspective

7.1. Introduction

With the presentation of the adaptation planning choices made by the Port of Rotterdam (Chapter 4), Port of San Diego (Chapter 5), and Naval Base Kitsap – Bremerton (Chapter 6), the next step is to evaluate the adaptation choices using the decision criteria developed in Chapter 3 for:

- Climate Scenario Choices
- Decision Support Tool Choices
- Adaptation Strategy Choices
- Planned Adaptation Actions
- Chosen Adaptation Planning Timeframe
- Adaptation Financing Choices

The adaptation choices for the Port of Rotterdam and Port of San Diego are summarized in tables in each section along with an evaluation of the "robustness" of each choice. The rationale for each of the determinations precedes the table. Although the original research intent was to analyze the adaptation choices for Naval Base Kitsap – Bremerton in this same manner, it was not possible to do so since the Navy's plans for NBK are far from complete. Instead, recommendations for Navy adaptation planning are based on the adaptation choices made in the commercial port case studies, observed best practices, and practical constraints.

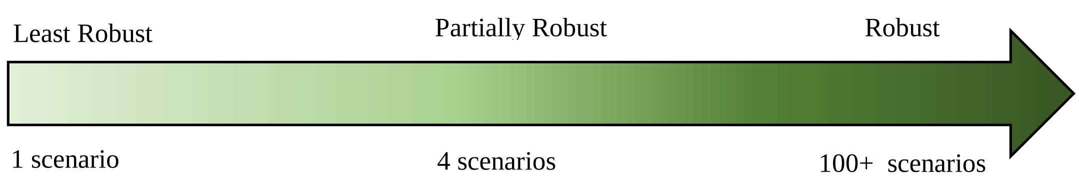
In light of the great uncertainties inherent to future climate change, it behooves organizations to make the most robust decisions possible to be prepared for a wide range of potential future climates (Lempert and Schlesinger 2000; Kalra *et al* 2014; Hallegatte 2009). However, organizations with overlapping responsibilities do not make the same choices due to divergent organizational priorities and beliefs.

By way of example, each section in this chapter analyzes the robustness of the adaptation choices made for the Port of Rotterdam by the Dutch national government, City of Rotterdam, and Port of Rotterdam Authority. It is necessary to examine all three together since their views differ regarding adaptation decision-making. Port Authority planners consider 2050 to be the furthest planning horizon they should reasonably consider (Eisma 2014), whereas the city and national government are planning for 2100 (Van Barneveld 2013; Ministry of Infrastructure 2014).

7.2. Robustness of Climate Scenario Choices

The following discussion is based on section 3.3.1 and Figure 3.1 (re-produced as Figure 7.1).

Figure 7.1. Robustness of climate scenario choice



7.2.1. Port of Rotterdam

The Dutch national government has conducted extensive, location-specific research to reduce the uncertainty associated with adaptation decision-making for the Port of Rotterdam (Knowledge for Climate 2014). Although the research reports partially reduced the uncertainties associated with climate change and The Netherlands, many questions remain. Consequently, the national government explicitly chose to not assign a probability distribution to the four socio-economic Delta Scenarios (see Figure 4.2), regarding each as equally likely to occur. In reality, the national government only suggested two climate scenarios with two socio-economic variants. Predetermining a small number of scenarios is the opposite of robust decision-making. Instead Kalra *et al* (2014) and Lempert, Popper, and Bankes (2003) emphasize the need to consider hundreds of possible scenarios. The probable result of only considering a small number of scenarios is economically inefficient decision-making (Bonzanigo and Kalra 2014), the last thing the Dutch would want in tough economic conditions. The national government at least partially mitigates the potential inefficiency by designing adaptation plans for acceleration or deceleration based on the latest climate change information, a hallmark of flexible, adaptive decisions embedded in a risk management context. In effect the Dutch government's approach treats the Delta scenarios more as decision thresholds rather than predictions of the future climate. In so doing the national government considers many more climate projections when making decisions than the four published scenarios. For these reasons, the national government's choice of climate scenarios is at least *partly robust*.

City of Rotterdam planners are well aware that future climate change is uncertain, and cite "uncertainty" many times in city plans and reports. However, this research project found the city does not consider the uncertainty of climate change projections in a systematic way. When questioned on the consideration of uncertainty within the city plans, a city planner emphasized that due to the nature of his position, "you must always make a choice" (Van Barneveld 2014), for governments cannot afford do to nothing (Van Peijpe *et al* 2012). Yet as noted in section 4.1.1, city planners are leery of over-building for climate change, and have chosen to rely upon a moderate climate scenario, "Busy," which only predicts sea level rise of up to 35 cm (13.8") in 2100. Still, by using only one climate scenario, city planners unnecessarily restrict their planning choices to those which are satisfactory in a single future climate. This choice is rated as *least robust*.

By not choosing a climate scenario due to a belief that the future is too uncertain, the Port of Rotterdam Authority made the most "robust" decision by default of the three entities concerned. Yet this potentially wise decision is fully negated by the port's inaction on the issue of planning for climate change. Based on the author's conversations with Port of Rotterdam Authority and City officials, the authority has no intention of planning more conservatively than the City. In consequence, it is expected that Authority will adopt the same climate scenario as the City. This stated preference is scored *least robust*.

The combined effects of the differing climate scenario choices are mixed. The Dutch national government is proceeding with its own plans of flexible, incremental adaptation based on the Delta scenarios, regardless of what the Port of Rotterdam and City of Rotterdam decide to do. The City of Rotterdam and the Port of Rotterdam Authority are more closely linked; whichever organization makes the least robust scenario choices will overshadow the other. Overall, the net effect of the climate scenario choices is *minimally robust*.

7.2.2. Port of San Diego

The Port of San Diego has indicated that it will rely upon the four climate scenarios first published in the 2012 *Sea Level Rise Strategy for San Diego Bay* (Hooven 2015). The Port is funding a detailed hydrodynamic model to more accurately portray wave action and sea level rise within San Diego Bay. Although this model will allow Port of San Diego planners to make more informed adaptation plans using the scenarios, it will not improve the robustness of the adaptation choice of four basic climate scenarios. A probability distribution has not been assigned to any of the scenarios, allowing decision-makers to decide which scenario to use based on the infrastructure or function at risk. Measured on Figure 3.1, this is only a *partly robust* choice at best.

7.2.3. Recommended Choice for Navy Planners

As discussed above, the climate scenario choices for the Port of Rotterdam are only *minimally robust*, whereas for the Port of San Diego the choice is *partly robust* (see Table 7-1). According to Figure 3.1, the most robust choice is to develop hundreds or thousands of scenarios using substantial computing power, large amounts of quantitative data, and expert knowledge, yet as discussed in section 2.4.3, doing so is beyond the normal capacity of most organizations (Hallegatte 2009). This is especially true of NAVFAC Public Works Departments, which are limited by time, funding, and organizational expertise, and must make the best decisions they can with the resources available.

As a result, the recommended scenario choice is to adopt the pragmatic methodology of the Dutch national government: develop a small set of climate scenarios considered equally likely to occur, then continually test adaptation plans against the scenarios as an on-going robustness test. Scenarios should be regularly updated as new information becomes available. In this way the scenarios function as decision tipping points or thresholds which facilitate flexible, adaptive decision-making. This solution, more practical than perfect, is not fully robust due to the drawbacks mentioned in section 7.2.1. For these reasons the recommended adaptation choice for Navy planners regarding climate scenarios is *partly robust*.

Table 7-1. Summary of Climate Scenario Choices

Entity	Climate Scenario	Robustness of scenario choices	Overall Robustness of Choice
Dutch National Government	No scenario favored (out of 4 published). 35 cm (13.8”) - 85 cm (33.5”) sea level rise in 2100	Partly Robust	Minimally Robust
City of Rotterdam	“Busy” scenario with 35 cm (13.8”) sea level rise in 2100	Least Robust	
Port of Rotterdam	None chosen.	Least Robust	
Port of San Diego	2050: 0.5 m (20”) sea level rise + 100-year extreme event 2100: 1.5 m (59”) sea level rise + 100-year extreme event	Partly Robust	Partly Robust
Navy (recommended)	No scenarios favored. Use a series of scenarios as decision thresholds for flexible, adaptive decision-making.	Partly Robust	Partly Robust

7.3. Robustness of Decision Support Tool Choices

The discussion in this section is based on section 3.3.2 and Table 3-4 (re-produced as Table 7-2).

Table 7-2. Rubric for evaluation decision support tools
(Adapted from Dessai and van der Sluijs 2007, 60)

Frameworks for decision-making under uncertainty	Statistical Uncertainty	Scenario Uncertainty	Recognized Ignorance & Total Ignorance
Decision support tool 1 (example)	-	+	++
Decision support tool 2 (example)	++	+	+/-

Legend: ++ very good; + good; +/- neutral; - bad; -- very bad

7.3.1. Port of Rotterdam

In the attempt to validate the Delta Program, cost-benefit evaluations were of primary importance, integrated problem analyses were secondary, and cost-effectiveness analyses were tertiary (Van Barneveld 2014; Ministry of Infrastructure 2014).[40] The validation process highlighted the uncertainty of long-term financial analyses due to variation in discount rates for adaptation action as well as climate uncertainty. Historically Dutch officials have used a 5.5% discount rate, but as the *2015 Delta Program* acknowledges, this rate is problematic when calculating the present value of benefits and costs which may not be realized until generations later (Lind 1995). The national government is conducting further research into the matter, and appears inclined to select a discount rate which decreases over time (Ministry of Infrastructure 2014), placing costs and benefits in the very long term on more equal footing.

The national government's current decision support tools choices are *minimally robust* when considered collectively (see Table 7-3). As noted in section 4.5.2, a cost benefit analysis with a fixed discount rate only yielded a slightly positive result over the long term for replacing the Maeslant Barrier. What if the discount rate changed slightly? Or sea level rise decelerated? Would the analytical results be the same? In this case the influence of statistical uncertainty for the Maeslant Barrier costs and benefits can be calculated, but scenario uncertainty is problematic for cost estimation, recognized and total ignorance even more so. If one cannot assign a probability to future costs and benefits, an accurate and objective cost-benefit analysis under conditions other than statistical uncertainty cannot be completed (Weitzman 2009, 18). Cost effectiveness analysis has essentially the same traits with respect to tolerating uncertainty due to its same reliance on predictable future conditions.

[40] The national government considered real options analysis approach (ROAA) for the Delta Program, but chose not to use it for unstated reasons.

The strength of integrated problem analysis (IPA) is a focus on linkages between causes and environmental impacts, rather than assigning probabilities to future events. This allows officials to focus on making decisions rather than striving for agreement on assumptions (Kalra *et al* 2014). IPA does require understanding the relationships between systems, thus it does not fare well under conditions of ignorance when relationships are poorly understood, if at all.

The City of Rotterdam did *not* conduct a cost analysis when developing their adaptation strategy. This was a tactic to avoid political objections based on cost (Van Barneveld 2014) rather than an attempt to make more robust decisions. At the same time, however, this approach allowed city planners to think long-term, look beyond uncertain cost estimates, and specify adaptation actions which were soft, flexible, and synergized with other priorities. Essentially the city's process (referred to hereafter as the "reasonable person decision path")[41] results in a robust adaptation strategy developed using the knowledge and resources at hand (Hallegatte 2009). Although the reasonable person decision path (RPDP) does not follow the robust decision making schematic used by Lempert, Sriver, and Keller (2012), the outcomes of the RPDP are at least *partly robust* due to is RPDP's tolerance of statistical and scenario uncertainty. The author judges RPDP neutral towards recognized ignorance, though RPDP is not robust to the black swans of total ignorance.

The City of Rotterdam completes the Rotterdam Societal Cost Benefit Analysis (RSCBA) for small-scale projects, though this method is judged *partly robust* at best. Similar to a cost-effectiveness analysis, RSCBA relies upon probabilities of future conditions to make

[41] RPDP is a term developed by the author.

comparisons between alternatives, rendering it susceptible to scenario uncertainty and all conditions of ignorance.

The Port of Rotterdam Authority has not chosen a decision support tool for adaptation decision-making, though the Authority's traditional choice for capital improvement planning, lifecycle analysis (a form of cost-benefit analysis) is *not robust*. Lifecycle analysis does well with statistical uncertainty, but is not effective under conditions of scenario uncertainty or ignorance, both recognized and total (Weitzman 2009, 18).

The combined effect of the varied decision support tools is mixed. No entity dictates the methods used by the others, though cost-benefit analysis for national projects is required by law (Kuipers 2014; Van Barneveld 2014). Further, none of the decision support tools are common to all project assessments, preventing direct comparisons and inhibiting redundancy of analysis. Overall the author judges the net effect of the decision support tool choices for the Port of Rotterdam as no more than *partly robust*, the level independently achieved by the robust person decision path and integrated problem analysis.

7.3.2. Port of San Diego

Although Port of San Diego planners have indicated an interest in decision support tools which consider uncertainty, standard practice is still to use multi-criteria decision-making with an embedded lifecycle analysis (Hooven 2015). The criteria used in project evaluation extend beyond financial considerations to include non-monetary items, such as public benefits, congruence with the Port's strategic goals and Port Master Plan, and synergy with other port initiatives. The lifecycle element of the analysis performs fairly well under statistical uncertainty, and the inclusion of non-financial criteria partially support robust decisions under scenario uncertainty. This approach does not work well under conditions of ignorance.

7.3.3. Recommended Choice for Navy Planners

Taken collectively, the decision support tools for the Port of Rotterdam are *partly robust* at best; the Port of San Diego scores no better (see Table 7-3). As discussed in section 2.4.2, no decision support tool is robust under all conditions. Hence the need to combine decision tools and frameworks to make robust decisions under all conditions of uncertainty (Werners *et al* 2013; Hallegatte 2009; Hallegatte *et al* 2012; Whittington 2014). As a result, the author recommends Navy planners use at least two tools to make decisions under all types of uncertainty. The tools should be used consistently for all projects to facilities comparative analysis. A sensible choice is the reasonable person decision path utilized by the City of Rotterdam paired with a resilience decision framework (see Table 2-4 for uncertainty scores for resilience decision-making). When these two decision support tools are used together the composite result is a *robust* adaptation choice.

Table 7-3. Summary evaluation of decision support tool choices
(Adapted from Dessai and van der Sluijs 2007, 60)

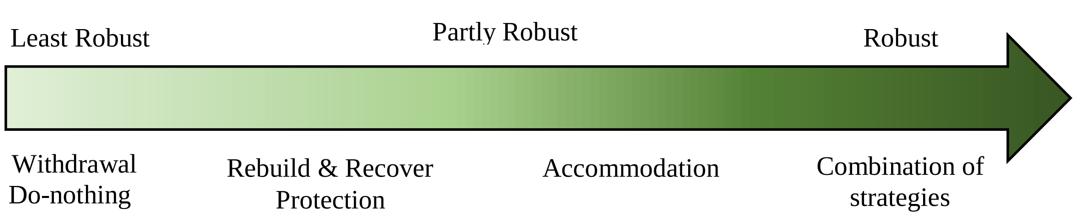
Entity	Frameworks for decision-making	Statistical Uncertainty	Scenario Uncertainty	Recognized Ignorance & Total Ignorance	Robustness of framework choices	Overall Robustness of Choice
Dutch National Government	Cost-benefit analysis (fixed discount rate)	+	-	--	Not robust	Partly Robust
	Cost-effectiveness analysis	+	-	--	Not Robust	
	Integrated problem analysis	+	+	--	Partly Robust	
City of Rotterdam	Reasonable person decision path	+	+	+/-	Partly Robust	
Port of Rotterdam Authority	Life-cycle analysis (stated preference)	+	-	--	Not robust	
Port of San Diego	Multi-criteria analysis with embedded lifecycle analysis	+	+	-	Partly Robust	Partly Robust
Navy (recommended)	Reasonable person decision path	+	+	+/-	Partly Robust	Robust
	Resilience	+/-	+	++	Partly Robust	

Legend: ++ very good; + good; +/- neutral; - bad; -- very bad

7.4. Robustness of Adaptation Strategy Choices

The subsequent analysis is based on section 3.3.3 and Figure 3.2 (re-produced as Figure 7.2).

Figure 7.2. Robustness of port adaptation strategy



7.4.1. Port of Rotterdam

The Dutch government's adaptation strategy, as far as it affects the Port of Rotterdam, is to protect as much as possible and accommodate only when necessary. On its face this is not a robust combination, since giant barriers and massive dikes are "hard," expensive choices in the name of protection. Due to the uncertainty in the speed and extent of climate shifts, the national government has favored an incremental, flexible approach for the Delta Program which allows plans to be accelerated or decelerated as needed (Ministry of Infrastructure 2014). In other words, doing less at less cost now, then doing more at a later date if required, is preferable to over-adapting during a period of limited government budgets. In this way the government's strategy "buys" time to make a more informed decision a later date, reducing decision horizons and increasing the robustness of an otherwise constrained strategy of protection. The result is a *partly robust* hybrid strategy.

The City of Rotterdam favorably compared its climate adaptation strategy of accommodation and local protection against the four Delta scenarios to evaluate its robustness to future climate change (Van Barneveld 2014). The author concurs, judging the city's approach at least *partly robust*. The Port of Rotterdam Authority's current adaptation strategy of doing nothing is *not robust.*

The combination of adaptation strategies choices by the three entities is complementary, yielding the three levels of flood risk management desired by the Dutch government (Ministry of Infrastructure 2014). This is a *robust* choice overall.

7.4.2. Port of San Diego

The Port of San Diego's inclination toward a strategy of accommodation is *partly robust*, though it falls well short of the combination strategy needed to achieve full robustness. The Port of San Diego is responsible for hundreds of millions of dollars of built infrastructure, and planning for all of this infrastructure to accommodate sea level rise is not a feasible alternative. A strategy of at least partial protection will likely be necessary. Furthermore, it is probably the port must yield at least partially on its stance of "no withdrawal" to carry out its mandate of ecosystem and habitat protection by allowing for upland habitat migration.

7.4.3. Recommended Choice for Navy Planners

The combined adaptation strategy for the Port of Rotterdam is *robust* overall, though unofficially favored Port of San Diego strategy is only *partly robust* (see Table 7-4). Given that all ports have large investments in infrastructure of varying functions, costs, and value, the ability to rely on any one adaptation strategy by itself is not only unlikely, but also partly robust at best. Therefore the author endorses the multi-level, flexible risk management strategy employed for the Port of Rotterdam, with its elements of protection, accommodation, and if necessary, rebuild and recover, as an appropriately *robust* choice of adaptation strategy for Navy planners.

Table 7-4. Summary of Adaptation Strategy Choices

Entity	Adaptation Actions	Robustness of Chosen Strategy	Overall Robustness of Choice
Dutch National Government	Protection and limited accommodation. Flexible implementation.	Partly Robust	
City of Rotterdam	Accommodation and local protection. Flexible implementation	Partly Robust	Robust
Port of Rotterdam	None chosen.	Not Robust	
Port of San Diego	Accommodation, no large-scale withdrawal (stated preferences).	Partly Robust	Partly Robust
Navy (recommended)	Combination strategy of protection, accommodation, and rebuild & recover.	Robust	Robust

7.5. Robustness of Planned Adaptation Actions

The analysis in this section is based on section 3.3.4. The criteria for measuring the robustness of each adaptation action are adapted from Hallegatte (2009):

- No-regret or low-regret
- Synergizes with other priorities
- Provides a cheap safety margin
- Reduces decision horizons
- Easily reversible/flexible
- Soft

7.5.1. Port of Rotterdam

To evaluate the robustness of the specific actions comprising the Delta Program, officials tested the measures against an even more rapid rate of climate change than projected by the worst case "Steam" scenario (Ministry of Infrastructure 2014). The assessment found the measures proposed in the Delta Program were sufficiently robust to a variable rate of climate change; implementation of the program could be accelerated or decelerated as the pace of climate change varied (Ministry of Infrastructure 2014). Such flexibility is a key characteristic of robustness (Hallegatte 2009).

Despite being flexible, the actions of the Delta Program are not necessarily those which are most robust to possible future climates. Level one of the flood risk management strategy (improving dikes and replacing barriers) are “hard” protection choices whose robustness can only be minimally improved by implementing cheap safety margins. Dutch planners have considered climate scenarios too uncertain to justify the multi-billion dollar cost of improving flood protection immediately, and have hesitated to initiate such measures (Veelen 2013). Instead planners have focused on flood risk management levels two and three, which involve “soft” accommodation measures, as much more robust choices given the current levels of uncertainty surrounding climate change. At this time the national government’s chosen adaptation actions are *partly robust*.

Although the City of Rotterdam conducted a similar “robustness” assessment by testing the validity of the city’s adaptation proposed adaptation actions against the four Delta scenarios, city planners are only relying on the low-end “Busy” climate scenario to guide implementation of adaptation actions. Despite the limits imposed by their reliance on a single climate scenario, City of Rotterdam planners are focusing primarily on small-scale “soft” actions, which increases the chances they will choose robust actions which meet one or more of the common-sense robustness criteria noted above (Hallegatte 2009).

Although the Port of Rotterdam Authority has not chosen any adaptation actions, the combination of robust and partly robust actions from the Dutch national government and the City of Rotterdam form a *robust* whole in the judgment of the author.

7.5.2. Port of San Diego

Few specific adaptation actions have been chosen for land within the Port's planning area. These actions, which apply to only the Chula Vista Bayfront, are accommodation measures for new development. Many choices still need to be made for the existing infrastructure for which the Port of San Diego is responsible as well as the utility networks, local streets, and commercial buildings which are located on port property yet owned by other entities. More generally, the Port tacitly adopted two of the "soft" adaptation actions listed in the 2012 *Sea Level Rise Strategy for San Diego Bay*: form a regional, staff-level sea level rise working group and pursue research on vulnerabilities and impacts of potential sea level rise. The overall rating of these adaptation choices is *not robust*. Much more needs to be done, particularly in regards to existing Port of San Diego infrastructure, but officials are moving towards selecting a robust set of adaptation actions.

7.5.3. Recommended Choice for Navy Planners

The combination of adaptation actions for the Port of Rotterdam is *robust*, though San Diego has not made chosen enough adaptation actions to score other than *not robust*. Overall the choices by each of the ports are well-reasoned, and all possess at least two of the robustness characteristics from Hallegatte (2009). These logical choices form the basis of the recommended adaptation actions for Navy infrastructure (see Table 7-5). The intent of suggesting a combination of adaptation actions is to demonstrate that actions which are partly robust individually, form a fully robust response when in adopted in combination. However, no group of adaptation actions can be fully robust when evaluated out of context. Every Navy port is different, with unique constraints, functions, and infrastructure. A robust suite of adaptation actions must be developed and carefully validated on a location-specific basis.

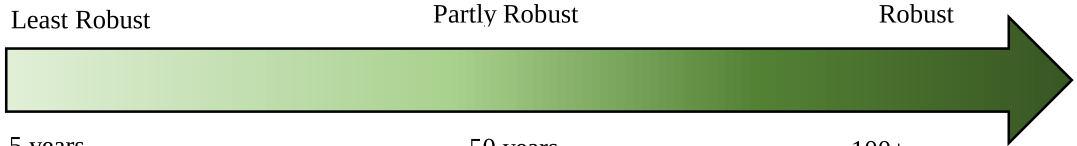
Table 7-5. Summary of Adaptation Action Choices

Entity	Adaptation Actions	No/Low Regret	Synergy with other priorities	Cheap Safety Margin	Reduce decision horizon	Reversible / Flexible	Soft	Robustness of Chosen Actions	Overall Robustness of Choice
Dutch National Government	"Hard" protection measures (dikes, barriers).			x	x			Partly Robust	Robust
	New flood control and risk management policies.	x	x			x	x	Robust	
	Limited "soft" accommodation (increased risk tolerance)	x				x	x	Partly Robust	
City of Rotterdam	New flood control and risk management policies.	x	x			x	x	Robust	
	Local protection of critical infrastructure and functions.			x	x			Partly Robust	
	Adaptive development in flood-prone areas.	x	x	x	x	x		Robust	
	Improve disaster response.	x	x			x	x	Robust	
Port of Rotterdam	None chosen.							Not robust	
Port of San Diego	Small-scale withdrawal (upland buffers)	x	x	x	x	x	x	Robust	Not Robust
	Higher base floor elevations in Chula Vista.			x	x			Partly Robust	
	Regional sea level rise working group	x	x				x	Partly Robust	
	Research vulnerabilities and impacts	x	x		x	x	x	Robust	
Navy (recommended)	Adaptive development in flood-prone areas.	x	x	x	x	x		Robust	Partly Robust
	Local protection of critical infrastructure and functions.			x	x			Partly Robust	
	New flood control and risk management policies.	x	x			x	x	Robust	
	Regional sea level rise working group	x	x				x	Partly Robust	
	Research vulnerabilities and impacts	x	x		x	x	x	Robust	

7.6. Robustness of Chosen Adaptation Planning Timeframe

The following analysis is based on section 3.3.5 and Figure 3.3 (re-produced as Figure 7.3).

Figure 7.3. Robustness of planning timeframe choice



7.6.1. Port of Rotterdam

The Port of Rotterdam Authority's focus on planning for no further than 2050 (Eisma 2014) is not sufficiently far-sighted given the long-term risk of climate change (Whittington and Young 2014). Planning for the very long-term allows the consideration and selection of adaptation measures which are sufficiently robust to withstand a wider range of potential future climates (Whittington and Young 2014). Given the long-life of many infrastructure systems (Hallegatte 2009), only by looking to 2100 and beyond will the port be able to make robust planning choices.

The Dutch national government and the City of Rotterdam grasp this idea, and are planning for 2100 and beyond (Ministry of Infrastructure 2014; Van Barneveld 2013). The adaptation planning time horizons for both the city and that national governments are *robust*, whereas the Port's preferred choice of 35-years (at most) is *not robust.*

7.6.2. Port of San Diego

The Port of San Diego intends to plan for the year 2100 (Hooven). This is a *robust* choice (Whittington and Young 2014).

7.6.3. Recommended Choice for Navy Planners

The selection of 2100 as a planning timeframe by the Port of San Diego is a robust choice, the choice of 2100 and beyond by the Dutch authorities even more so. The author recommends the Navy make a similarly *robust* choice of 2100 for planning purposes. Future climate projections become even more speculative after 2100, and lose value for detailed planning. Furthermore, most Navy infrastructure is not designed to last beyond a 75-year service life, though Hallegatte (2009) rightly notes certain infrastructure decisions (e.g., siting of ports and bridges) require a much longer timescale. In those special situations, a robust choice would be to use a planning timeframe in excess of 100 years.

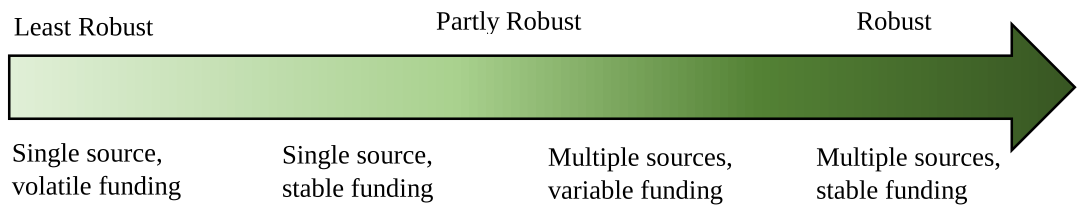
Table 7-6. Summary of Adaptation Planning Timeframe Choices

<table>
<tr><th>Entity</th><th>Planning Timeframe</th><th>Robustness of Choices</th><th>Overall Robustness of Choice</th></tr>
<tr><td>Dutch National Government</td><td>2100 and beyond</td><td>Robust</td><td rowspan="3">Robust</td></tr>
<tr><td>City of Rotterdam</td><td>2100 and beyond</td><td>Robust</td></tr>
<tr><td>Port of Rotterdam</td><td>2050 (stated preference)</td><td>Not Robust</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Port of San Diego</td><td>2100</td><td>Robust</td><td>Robust</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Navy (recommended)</td><td>2100</td><td>Robust</td><td>Robust</td></tr>
</table>

7.7. Robustness of Adaptation Financing Choices

The subsequent analysis is based on section 3.3.6 and Figure 3.4, (re-produced as Figure 7.4).

Figure 7.4. Robustness of adaptation financing choice



7.7.1. Port of Rotterdam

The Dutch government guaranteed funding for the Delta Program from the national budget through 2028 (Ministry of Infrastructure 2014). This single-source funding choice is only *partly robust* since it is still subject to annual appropriation and political exigencies. Adaptation financing for the City of Rotterdam is even less robust. Implementing adaptation is not even a major budget line item (Van Barneveld 2014), and small-scale projects have only been implemented on an opportunistic basis. Without a more stable funding mechanism, the ability of the City of Rotterdam to fully implement its adaptation strategy is uncertain. Consequently, this choice is rated *least robust*.

The Port of Rotterdam Authority has not identified a funding source for climate change adaptation. However, the ability of the port to rely upon funding from commercial companies (e.g., leases and berthing fees), utilities, and potentially the city and national governments, suggests the port's potential financing sources are *partly robust* at a minimum, and robust at best.

The lack of guaranteed funding for adaptation purposes reduces the robustness of the financing available to the port.

The financing choices for adaptation at the Port of Rotterdam are at least *partly robust* when considered collectively. Multiple parties contribute from multiple funding sources, and no entity or government bears all costs. On the other hand, the sources of funding are variable, and none are guaranteed.

7.7.2. Port of San Diego

The Port of San Diego currently earns revenue from commercial leases and service fees (Hooven 2015). The Port also has the authority to levy taxes – and sell bonds secured by taxes – to fund necessary climate change adaptation measures. Port officials may also apply for state and federal grants. Though the Port does not control funding for infrastructure owned by others, such as local streets and utilities, the Port is not responsible for paying for adaptation of this infrastructure, either. When viewed holistically, the Port's adaptation financing options are *robust*.

7.7.3. Recommended Adaptation Planning Choice for Navy Planners

The most robust financing choice is to secure stable financing sources from multiple entities. Both ports have this freedom, though the Port of San Diego's financing options are particularly robust. However, the Navy's ability to pursue multiple funding sources is constrained, for several funding options dedicated to the Port of San Diego are not available to a federal agency. Instead the author recommends the Navy pursue DOD infrastructure funding of various types to fund climate change adaptation actions. At best the recommended choice is only *partly robust*, a reflection of the limited number of funding mechanisms available to the Navy.

Table 7-7. Summary of Adaptation Financing Choices

	Financing Choice	Robustness of Choices	Overall Robustness of Choice
Dutch National Government	Delta Program budget through 2028	Partly Robust	Partly Robust
City of Rotterdam	Annual city budget	Least Robust	
Port of Rotterdam	Companies using port, city & national governments, utilities	Partly Robust	
Port of San Diego	Port revenue (leases, fees, bonds, taxes), city governments, utilities, state and federal grants	Robust	Robust
Navy (recommended)	Multiple types of federal funding.	Partly Robust	Partly Robust

7.8. Summary of Recommended Choices for Navy Planners

Examining the adaptation choices for the Port of Rotterdam and Port of San Diego from a robustness perspective yielded a series of six recommended adaptation choices (see Table 7-8).

Table 7-8. Recommended adaptation planning framework for Navy planners

Adaptation Choice	Recommended Choice	Robustness of Recommended Choice
Climate Scenario	No scenarios favored. Use a series of scenarios as decision thresholds for flexible, adaptive decision-making.	Partly Robust
Decision Support Tool	Combination of decision support tools: Reasonable person decision path and Resilience.	Robust
Strategy	Combination strategy of protection, accommodation, and rebuild & recover.	Robust
Actions	Adaptive development in flood-prone areas. Local protection of critical infrastructure and functions. New flood control and risk management policies. Regional sea level rise working group Research vulnerabilities and impacts	Partly Robust
Planning Timeline	2100	Robust
Financing	Multiple types of federal funding.	Partly Robust

Notably, only three of the six choices qualify as robust using the metrics developed within this paper. Although always making robust choices is better than not, doing so is likely beyond the capability of most organizations, NAVFAC Public Works Departments included. All governments operate under constraints of time, money, and personnel, compelling officials to make decisions which will perform well in most circumstances over waiting for the right opportunity to make the best possible decision. In other words, the recommended planning framework values the pragmatic choice over the perfect selection – a robust framework, as it were.

8. Discussion

8.1 Findings

The ultimate purpose of this study was to assist U.S. Navy with making decisions regarding adaptation of coastal infrastructure to climate change. The findings suggest studying adaptation choices by other entities, and evaluating the choices from a robustness perspective, is a reasonable approach to addressing the complicated problem of climate change adaptation. In this study, the adaptation planning choices made by the Port of San Diego and Port of Rotterdam provided a reasonable basis for comparison to the adaptation challenges faced by a U.S. Navy port. Analyzing adaptation choices made at Naval Base Kitsap – Bremerton was not possible since very little adaptation planning has occurred. Fortunately, analysis of the commercial ports' adaptation choices yielded an adaptation planning framework for all Navy bases to follow (see Table 7-9).

Whether the framework proves useful is an open question. The U.S. Navy is proceeding apace with its own adaptation decision-making framework, and whether this thesis can influence the process is, like climate change, uncertain. Even so, a planning framework based upon robust adaptation choices is promising approach to climate change adaptation planning.

8.2 Limitations and Generalizability

8.2.1 Data Sources

In this study quantitative data was not a primary focus, and numerical precision and accuracy was not a concern. Instead this project relied upon published documents and semi-structured interviews, all of which are subject to the qualitative opinions of authors and interviewees, respectively. Additionally, due to the incompleteness of adaptation planning at each of the ports studied, ancillary plans and information had to be included to create a more comprehensive picture of current state of adaptation planning at each port. Frequently this meant relying upon "stated preferences," rather than more useful "revealed preferences," to explain what port officials *planned* to do to adapt to climate change, rather than what port officials *did* to adapt to climate change. This reliance supporting information was stronger for the Port of San Diego, which has not published a comprehensive adaptation strategy, nor have the cities surrounding San Diego Bay.

8.2.2. Methodology

For this project, the primary research methods of document review and interviews were successful in procuring a large quantity of information on adaptation planning at the ports studied. Due to the incompleteness of adaptation planning at each of the ports, a full analysis of each of the key adaptation planning choices was not possible. This led to reliance upon statements by planners and stakeholders regarding the direction of adaptation planning by a port, which has the obvious deficiency of assuming omniscience by those consulted. Although all interviewees were facilities and planning staff of the organizations involved, none had ultimate control or influence over climate change adaptation planning decisions. Although a port planner stating, "The port will do this…." sounds definitive, such a statement is uncertain until the decision is made by the appropriate official and the adaptation choice formally made. Only then can the theoretical robustness of an adaptation planning choice be effectively judged.

In addition, the evaluation of the robustness of adaptation choices is limited by the author's own knowledge and experience. What appears a robust choice to the author may not seem so to another observer. Hence, every attempt was made to explain the evaluation methodology and reasoning as fully as possible so that another investigator to could follow the same process and form their own conclusions.

This project also required simplification of the adaptation planning process in order to tease out the key adaptation choices made by ports. Many decisions large and small must be made in the course of climate change adaptation planning in addition to the six highlighted here. Although the net result of this project is a general adaptation planning framework intended for usage at any Navy base worldwide, the framework does not support development of detailed plans. Intensive, in-depth research is still necessary for development of a climate change adaptation plan for a specific location. For example, the framework recommends a robust group of adaptation actions without any consideration of local conditions, which must obviously be included when developing a workable adaptation plan.

8.2.3. Transferability

The project intent was to develop a general adaptation planning framework for Navy use. This goal has been achieved, for the planning framework outlined in section 7-9 can indeed be applied to Navy bases. Ports everywhere have similar infrastructure, and face similar risks from climate change. However, the missions and functions of the commercial ports studied differ markedly from a Navy port, thus the adaptation choices made by the Ports of Rotterdam and San Diego are not directly comparable to those which a Navy port might make. For example, the Port of San

Diego places great value on protection of natural functions, even at higher costs, sacrificing robustness in the process. In addition, the Navy operates under different planning, funding, and operational constraints, hence a robust planning choice for a commercial port may not be possible for Navy planners to consider, and a less robust choice must be made.

This thesis did not determine if this planning framework is superior to other planning frameworks, such as those developed by Scott *et al* (2013), the U.S. Army Corps of Engineers (2014a), ICLEI-Local Governments for Sustainability USA (Hirschfeld and Holland 2012). Climate change adaptation planning is a new field of applied research, and it is too soon to compare one planning framework to another to determine which is most effective in guiding an organization planning to adapt to climate change. Furthermore, the author would argue decisions made using a planning framework is more dependent on the skill, experience, and judgment of the people using it than the framework itself. A framework is merely a guide to assist decision-makers with their difficult task, and ultimate success or failure depends upon people rather than process.

9. Conclusion

9.1. Summary of Findings

Long-term planning in anticipation of climate change is now an inseparable part of infrastructure planning. While the U.S. Navy recognizes the potential impacts of sea level rise and other climate changes on coastal infrastructure, guidance directing Navy planners on how to prepare for climate change has not yet been published. Consequently, this project undertook a comparative analysis of adaptation planning choices made for the Port of San Diego, Port of Rotterdam, and Naval Base Kitsap – Bremerton in order to discover a robust yet practical adaptation planning framework which the U.S. Navy might use for its coastal bases.

This project analyzed six key adaptation choices for the ports from a robustness perspective: climate change scenarios, decision support tools, adaptation strategy, adaptation actions, adaptation funding sources, and adaptation planning timeframe. Each of the ports' adaptation choices was evaluated using a literature-based methodology, the results of which informed recommendations of the most robust planning choices the U.S. Navy could practically make. Although this thesis found Naval Base Kitsap – Bremerton has not conducted any formal adaptation planning, the results from studying the commercial ports in Rotterdam and San Diego were sufficient to develop an adaptation planning framework for all Navy bases.

Overall, a planning framework based upon the robustness of adaptation choices made for ports is a promising approach to climate change adaptation planning. The comparative study found the most robust yet practical climate scenario is use a series of scenarios as decision thresholds for flexible, adaptive decision-making. The most robust decision support tool is a combination of methods which are tolerant of uncertainty, such as the reasonable person decision path and resilience planning. The recommended adaptation strategy is a combination of protection, accommodation, and rebuild and recover approaches. A complete list of recommended adaptation actions is location-dependent, though certain actions are robust regardless of location and rate and extent of climate change. Practical, robust recommendations for adaptation planning timelines and financing are the year 2100 and multiple types of federal funding, respectively.

9.2. Potential for Future Study

A common theme in the literature is the need for adaptation plans to be flexible and adaptive to a changing climate. At the same time, no adaptation process and plan are "proven to work" under all circumstances. In fact, this study did not find a single article, study, or climate adaptation plan which has been proven to work. This is not to suggest climate change is not occurring (it is), or adaptation cannot work (it can). Rather, the paucity of evidence suggest that it is far too soon to evaluate what adaption planning methods and measures will work best to adapt to a changing climate. Therefore a ripe area for future research is investigating which adaptation measures are most cost-effective, less environmentally damaging, less difficult to implement, etc.

Given the nature of this project, a logical area for future study would be to apply the adaptation planning framework developed by this project to Naval Base Kitsap - Bremerton, and study the results years afterward. Which adaptation measures worked, and which did not? Did using the framework lead to increased costs in the short- or long-term? Did the framework save money by averting damage? Many relevant questions could be asked and answered in the course of such a study.

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Appendix A. Discussion Questions

1. **Which climate change scenario(s) did the Port/Navy choose to rely upon to make adaptation decisions?**
    a. Method: Review of current plans and policies; Stakeholder interviews.
        i. Which climate change scenarios were reviewed?
        ii. Which scenario was used for decision-making? Why?
        iii. Which Port/Navy infrastructure is at risk based on the chosen climate change scenario?

2. **Which adaptation goal(s) did the Port/Navy choose?**
    a. Method: Review of current plans and policies; Stakeholder interviews.
        i. Which policies (national, regional, local) affect climate change adaptation planning for the Port/Navy?
        ii. What was the process followed to develop the goals?
        iii. What are the goals of the plan?
        iv. Why were those goals chosen?
        v. How were stakeholders (agencies/institutions/governments) engaged regarding these goals?

3. **Which decision-making methodology did the Port/Navy choose to make adaptation decisions?**
    a. Method: Review of current plans and policies; Stakeholder interviews.
        i. Which entity (if not the Port/Navy) is responsible for adaptation decision-making?
        ii. Which decision-making method did the Port/Navy choose?
        iii. Why was that method chosen?
        iv. How robust is the decision-making method?
        v. How does the Port/Navy address uncertainty in decision-making?

4. **Which adaptation priorities did the Port/Navy choose?**
    a. Method: Review of current plans and policies; Stakeholder interviews.
        i. Which adaptation priorities were chosen?
        ii. Why were they chosen?
        iii. How are adaptation priorities incorporated in the Port/Navy's capital improvement program (CIP)?
        iv. What is the Port/Navy's CIP process, including funding?

5. **What adaptation actions did the Port/Navy choose?**
    a. Method: Review of current plans and policies; Stakeholder interviews.
        i. Which adaptation actions did the Port/Navy choose?
        ii. Why were those actions chosen?
        iii. How have these actions been incorporated into the CIP?

6. **What adaptation timeline did the Port/Navy choose?**
    a. Method: Review of current plans and policies; Stakeholder interviews.

i. What is the adaptation timeline?
ii. Why was that timeline chosen?
iii. When will the adaptation plan be re-evaluated?

7. **What funding source did the Port/Navy choose to finance implementation of their adaptation plans?**
   a. Method: Review of current plans and policies; Stakeholder interviews.
      i. Which funding sources are available to implement the adaptation plan?
      ii. Which funding source(s) did the Port/Navy choose?
      iii. Why was that funding source chosen?