Application of International Approaches to Sea Level Rise to Strategies for Boston

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Abstract

Sea level rise is an international challenge, with many countries facing potentially millions of lives affected and billions of dollars in losses. Boston has started to evaluate its own vulnerabilities but can learn from the way other cities have approached the issue. This addendum presents major steps other countries have taken to sea level rise protection measures and compares them to the United States and Boston. Recommendations are made for Boston's future planning efforts and projects to efficiently and effectively address the impacts that arise from sea level rise in the city.

This addendum has been submitted with an updated version of the jointly authored report for this Major Qualifying Project: Chase Gaudino, Lauren Kaija, Emilia Perez, Hannah Schulz, Trisha Worthington "Preparing for the Rise: A Study of Boston's Sea Level & Designs for Coastal Resiliency." An earlier version is available: https://digital.wpi.edu/show/m326m444v

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Key Terms and Abbreviations

CEWP – China Europe Water Platform
CRB – Climate Ready Boston
CZM – Coastal Zone Management
FEMA – Federal Emergency Management Agency
IPCC – Intergovernmental Panel on Climate Change
MOSE – Modulo Sperimentale Elettromeccanico (Electromechanical Experimental Module)
NOAA – National Oceanic and Atmospheric Administration
RCP - Representative concentration pathway
SCC – Sponge City Concept
SIDS – Small Island Developing States
SROCC – Special Report on the Ocean and Cryosphere

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1.0 Climate Change Across the Globe

Outlooks and attitudes towards climate change vary widely from country to country, state to state, and community to community. There is endless debate over whether climate change is real, human-caused or natural, and who, if anyone, is responsible for addressing it. Regardless of these debates, many countries are feeling the effects of a shifting climate in the form of extreme temperatures and weather events. One such threat is rising sea levels, which poses the highest risks to cities in Southeast Asia, as well as coastal cities such as Miami and New York (Hanson, et al., 2010).

Each city takes a different approach to mitigating its vulnerability to rising sea levels and extreme storm events based on public attitudes and government initiatives. Every nation in the world is at a different point in development socially, economically, politically, and environmentally. A country's preparation for sea level rise and climate change is often as a function of how severely or directly affected they will be by the consequences.

In 2019, the United Nations Intergovernmental Panel on Climate Change (IPCC) released the Special Report on the Ocean and Cryosphere (SROCC). This is the first report since the Panel's inception in 1988 and serves a very important purpose for countries moving forward, as 71% of Earth's total surface area is water (frozen, freshwater, or ocean). The nearly 800-page IPCC report (along with supplementary material) came as a result of requests from national governments concerned about insufficient data on the topic. The report details major scientific data points on climate effects to water and ice on land and in oceans, beyond melt and rising sea levels. It also offers adaptation measures and resilience and risk management response options to be considered. In short, climate impacts to the hydrosphere are extremely complex and interconnected. Humans face food and water security challenges now and in the future, and some are more harshly and unequally impacted than others.

Figure 1 depicts a projection for the regional mean sea level changes between 2081-2100 according to a specific representative concentration pathway (RCP, carbon emissions scenario). It is important to note the coastal megacities, Small Island Developing States (SIDS), and deltas that are particularly at high risk of sea level rise.

Historically, international legislation on climate change came to the forefront of political agendas with the Montreal Protocol, followed by the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and finally the Paris Agreement (Maizland, 2021). The science behind climate change is rather widely accepted at this point, but the best way to move forward in addressing it is not. For this reason, it is better to look at the legislation, policies, and projects independently put forth by nations, and evaluate based on their individual success.

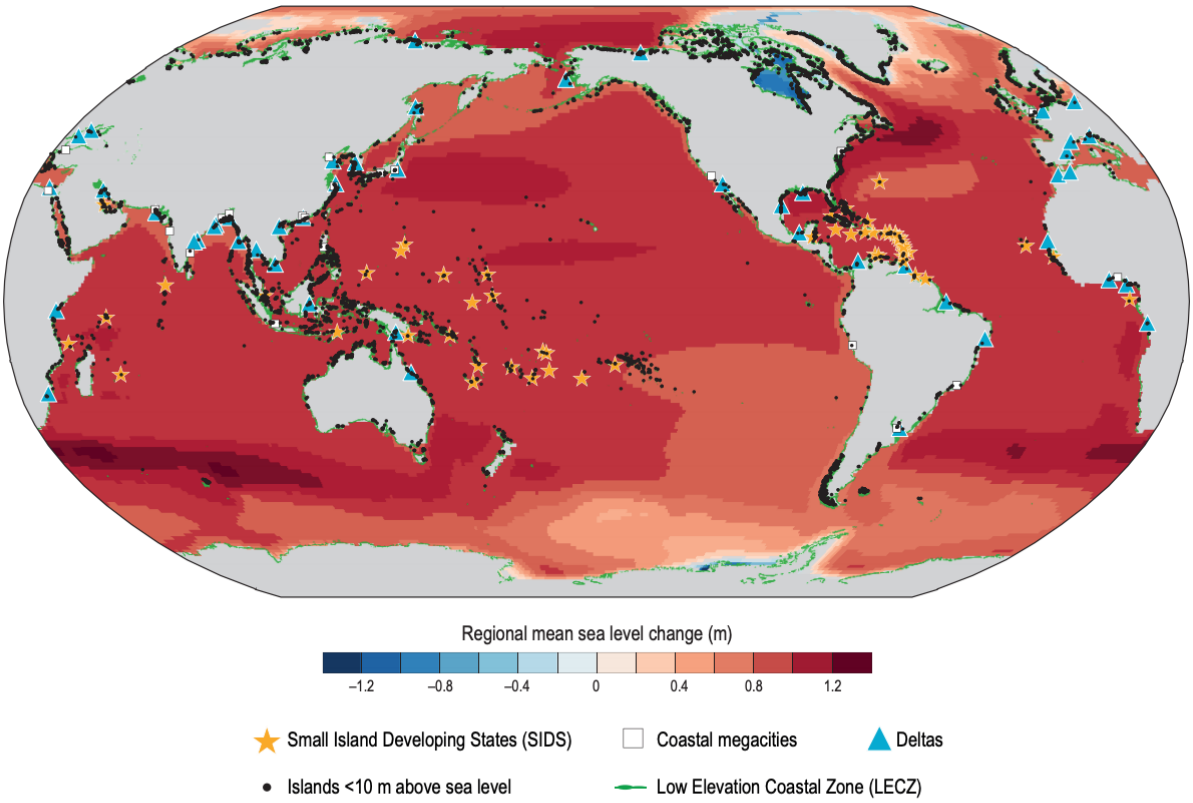

Figure CB9.1 | The global distribution of low-lying islands and coasts (LLIC) particularly at risk from sea level rise. This map considers the Low Elevation Coastal Zone (elevation data from National Geophysical Data Center, 1999; LECZ, defined by McGranahan et al., 2007), islands with a maximum elevation of 10 m above sea level (Weigelt et al., 2013), Small Island Developing States (SIDS; UN-OHRLLS, n.d.), coastal megacities (cities with more than 10 million inhabitants, within 100 km from coast, and maximum 50 m above sea level; Pelling and Blackburn, 2013; UN-DESA, 2018) and deltas (Tessler et al., 2015). Regional sea level changes refer to projections under Representative Concentration Pathway (RCP)8.5 (2081–2100) (see Figure 4.8).

Figure 1: Regional Mean Sea Level Changes between 2081-2100 (IPCC, 2019)

Section 2.0 of this report details political, societal, and technical approaches to sea level rise protection measures in the United States. Section 3.0 presents case studies of the Netherlands, China, and other notable sea level rise projects around the world. Gaining insight on the successful accomplishments of other countries should inform options in the United States. Thus, Section 4.0 compares and contrasts these case studies to approaches in the United States. Significant differences between government policy, citizen involvement, and engineered approaches are highlighted. Finally, Section 5.0 sets forth recommendations and conclusions about the current status and future directions for climate adaptation in Boston.

2.0 Sea Level Rise Approaches in the United States

For comparison against international strategies, methods of dealing with sea level rise in the United States must be examined on national, regional, and community scales. Scale is important, as some whole countries are smaller than a single city in the United States. Impacts of climate change have traditionally fallen below other priorities in the nation's list of top concerns. Regardless of why this is the case, the strictness of federal and state policies related to sea level rise vary widely from each other and those of other countries, which has dangerous implications for the future. If the impact of sea level rise on US coasts is not emphasized and acted upon, the country will continue to see more damage and economic loss as a result of flooding and extreme weather events.

2.1 Government Policy and Citizen Involvement

It is very easy to get lost in the executive offices, departments, agencies, sub-agencies, bureaus, boards, commissions, and committees that make up the executive branch of the US government. The governing bodies that most directly influence coastal policy are often found within the layers of other parent agencies.

The National Oceanic and Atmospheric Administration (NOAA) reports to the US Department of Commerce and operates the nation's Office for Coastal Management. The Office for Coastal Management is in charge of collaborating with each state to implement policy and support programs. The Federal Emergency Management Agency (FEMA), whose parent agency is the US Department of Homeland Security, is meant to protect from, prepare for, respond to, and mitigate hazards. FEMA operates the National Flood Insurance Program (NFIP), which provides insurance to property owners and works with communities on floodplain management regulations (Branches, 2021). Ultimately, most of the policy making and enforcement falls under state responsibility, with federal government providing overarching guidance and funding.

The Massachusetts Office of Coastal Zone Management (CZM), part of the Executive Office of Energy and Environmental Affairs, oversees hazard protection, preparation, response, and mitigation. The state has made steady progress in adapting to climate change and sea level rise, but it is increasingly evident that progress is not being made fast enough. Initiatives like the Massachusetts Hazard Mitigation Plan, StormSmart Coasts Program, and most recently Climate Ready Boston are attempts to better prepare the state for projected losses incurred from sea level rise and climate change. CZM has worked hard to empower communities and involve citizens in the planning process (Miller, Kaminski Leduc & Miller, 2012).

Most policy making, at a federal and state level, has been focused on housing and development regulations along coasts and in floodplains. However, economic growth interests often clash and prevent drastic changes or regulations at a level that might be seen in the Netherlands, for example. Public participation in the United States is often incorporated at a community level, such as town meetings and hearings through municipal governments. Yet

this participation becomes more difficult the higher up the policies and projects are discussed, such as in statehouses and federal organizations. This is where clashes continue to happen, when planning for recovery or future resiliency happens in a top-down manner. The struggle between taking action in an efficient manner and making sure actions are beneficial for and supported by those communities being affected continues to take place in many areas affected by flooding and sea level rise.

2.2 Technical/Engineered Approaches

In 2005, Hurricane Katrina hit New Orleans and is known as the biggest flooding disaster in the history of the United States. New Orleans has been subject to flooding throughout its history and rebuilding the community after the levees broke during Katrina highlighted longer-term disparities and inequalities based on race, class and environment (Horowitz, 2020). The level of damage New Orleans suffered woke the rest of the country up to what happens when coastal cities plan to reduce consequences of smaller, more frequent events, and in the process increase their vulnerability to much bigger and less frequent events (Kates, et al., 2006).

Rather than making immediate moves to fortify the area from future floods through defense infrastructure, major focus after Katrina was instead on how best to plan for a future for the city in which this level of disaster would not happen again. Recovery planning involved lots of public participation in hopes of ensuring equity for all demographics trying to recover. Some residents thought it was almost too much time spent planning. Furthermore, efforts were focused on "bettering" and reconstructing the levees and dams that were supposed to protect from flooding. In the 10 years since 2005, the federally-funded Army Corps of Engineers spent some $14.5 billion on constructing and repairing levees, floodgates, dams, and other flood protection systems along 350 miles of coastline (Burnett, 2015). Some of these systems are already sinking due to land subsidence. The cost was nothing compared to the economic damage caused by the hurricane: $125 billion (Institution of Civil Engineers, 2018). The system of defenses was designed to withstand a one-hundred-year storm, and in some places a 500-year storm. Overall, policy struggles have overshadowed the recovery process from Hurricane Katrina, which is why the city is still trying to get back on its feet today and pursue the most logical solutions to sea level rise and climate change for their city (Comfort, Birkland, Cigler, & Nance, 2010).

Superstorm Sandy hit New York City and the surrounding coastline in 2012, causing at least $50 billion in federal disaster relief funds to be allocated, making it the second most costly natural disaster in US history at the time (now it is 4th after Harvey and Maria in 2017) (Colburn, et al., 2015). Recovery followed a slightly different trajectory, as leaders realized creative solutions were needed to adapt the city to be more climate resilient. As the affected areas did not have very advanced systems of flood protection in the first place, immediate moves were not made to reconstruct.

Six months after the hurricane, a competition called Rebuild By Design was launched for engineers, scientists, businesses, and planners to come up with innovative projects to address the weaknesses that Sandy exposed. Six projects were chosen, all incorporating a combination of soft and hard infrastructure – ways to live with and adapt to climate change rather than fight it. The US Department of Housing and Urban Development allocated $920 million for the winning projects, which is only a fraction of the total federal disaster relief funding provided after the storm hit. The project receiving the biggest cut of funding ($335 million) was designed by a Dutch architecture firm (Cho, 2015). Throughout the recovery process, larger storm barriers like one that would extend from the western tip of Long Island to the New Jersey coastline have been a point of discussion and contention. Involvement of public and private entities and communities in the decision making and planning process makes for a much more dragged-out timeline than a less democratic process where the government makes a final decision and implements it.

Boston has not seen natural disasters at a similar intensity, but rather faces a different challenge in that it is built on top of a filled-in marshland. The city of Boston--like New Orleans, Shanghai, Venice, and Jakarta (mentioned later in this paper)--faces land subsidence as the groundwater table lowers combined with rising sea levels and high tides. The city was lucky to avoid major flood damages from Hurricane Sandy, as it missed high tide by five hours, but it was a wakeup call (along with Hurricane Irene in 2011) to the increasing severity of storms and climate change on the city.

Climate Ready Boston (CRB) is an initiative started by the city in 2016 to investigate the effects of climate change on the city and to plan for a more resilient and protected city in the future. CRB estimates that with a projected sea level rise of 36” by 2070, a single 1000-year storm would cost Boston at least $22 billion in damages. This number only accounts for damages due to coastal and riverine flooding, not other effects like stormwater runoff or impacts to energy and telecommunications systems. More recent projections for sea-level rise in Boston are now 48” by 2070, and the cost projections must be revised upwards (Climate Ready Boston, 2016).

In the past five years, CRB has grappled with what will be the most effective ways to protect and adapt the city to climate change. In 2017, a research team from UMass Boston looked at the feasibility of three large harbor-wide barrier designs. Figure 2 shows where the three options would be located. The designs mimicked similar harbor wide barriers in other parts of the world, incorporating floating sector gates (like the Maeslantkering discussed in Section 3.1.2) and vertical lift gates to achieve as close to natural flow conditions. The two most feasible designs had cost estimates ranging from $6-12 billion. The study was a collaboration between UMass Boston’s School for the Environment, Arcadis, the Urban Harbors Institute, the Woods Hole Group, and the Woods Hole Oceanographic Group. They ultimately concluded that it is more advantageous to pursue shore-based climate adaptation solutions rather than harbor-wide strategies. The cost effectiveness, community benefits, and adaptability to and protection against tidal and storm surge flooding of the shore-based

strategies far outweighed the harbor-wide. For this reason, CRB has continued to plan projects more focused on the resiliency needs of individual communities rather than a silver bullet solution for all of Boston (Sustainable Solutions Lab, 2018).

Figure 2: Barrier Alternatives in Boston Harbor (Sustainable Solutions Lab, 2018)

3.0 International Case Studies in Approaches to Sea Level Rise

The following locations for case studies were chosen based on the similarity and/or superiority in developmental advances of technology, culture, and policy related to sea level rise in the United States and Boston. The approaches that the countries in these case studies have taken to sea level rise are varied, informed, and ideally applicable to how Boston may be able to adapt.

3.1 The Netherlands

The Netherlands has been at the forefront of hydraulic engineering and coastal protection since the beginning of civilization along the coast of the North Sea. Today, over a quarter of the country is below sea level and one of the most vulnerable cities, Rotterdam, is 90% below sea level (Muggah, 2019).

The country has learned throughout its history that the best way to approach sea level rise is not to fight the water, but to live with it. This is the basis behind their approach to engineering as well as national social policies. From the beginning of the very first civilizations on the coast, the first task of survival has been to avoid flooded homes. It is not merely an inconvenience to their lives, but a way of life. For this reason, it makes sense to most of the Dutch public to spend tax dollars, time, and labor on projects and policies that will help them live safely with the water.

The length of the Netherlands coastline has fluctuated over the years, as land has been reclaimed by humans and taken back by the ocean. The Dutch have realized that shortening the coast as much as possible is the most efficient way to protect their land and homes. The map in Figure 3 shows the southern coast of the Netherlands, where the land is lowest and most vulnerable to sea level rise.

Figure 3: Location of 13 Delta Works projects (The Delta Works, n.d.)

In 1953, a flood that the Dutch still call "the Disaster" killed about 1800 people in this southwestern delta, where three major European rivers meet the ocean. The extent of the damage caused an immediate response from the national government, which formed the Delta Commission. This group was responsible for evaluating the damages and future risks and planning to prevent such disasters from happening again. In the words of Henk Ovink, the first and only Special Envoy for International Water Affairs for the Netherlands, a disaster cannot be prevented from happening, but one can be better prepared when it does happen.

3.1.1 Government Policy and Citizen Involvement

As previously mentioned, the Netherlands has learned to live with water for many years, and thus the topic is a natural priority for the national government. This is evident in the fact that they are the only country in the world to appoint a "Water Ambassador" (Henk Ovink) who advises the UN, 35 individual countries, and at least a dozen US cities. He is responsible for building connections and relationships between other influential governmental and private organizations, groups, agencies, and partners. His goal is to further ambition and initiative in both the Netherlands and abroad in water-related adaptation and awareness.

Ovink collaborates with four out of twelve Ministries in the Netherlands government, one of which being the Rijkswaterstaat, or the Ministry of Infrastructure and Water Management (Government, 2020). This ministry sets the policies and legislation that provincial and municipal authorities carry out, as well as the 21 regional water boards that exist to represent landowners/farmers and the inhabitants in the area. Representatives are elected but turnout is often low: historically, only 25% of voters have shown up at elections and those 25% often don't know the water boards' tasks and are not able to vote on any programs (just representatives) (Enserink, Kamps, & Mostert, 2003). The water boards have the ability to tax the residents they serve in order to fund the maintenance of water works such as polders and dikes. Furthermore, flood insurance is very rare in the Netherlands and almost irrelevant when looking at how the country has approached flood protection.

Ovink asserts that it is better to spend money on flood defense and infrastructure than to wait and spend often much larger sums on restoring losses after a flood event (Whitaker, 2018). Damage due to flooding is usually not covered by insurance companies, so towns and cities feel a greater responsibility for keeping their citizens safe with flood protection and adaptation measures (Runhaar, et al., 2012).

The fact that the Netherlands is a "consensus" culture influences the amount of public participation (PP) that goes into project planning and government initiatives. The amount/level of PP is also influenced by the size of the project, the stakeholders, and who is in charge of the project. There are opportunities to get involved if you know how to "pull the right strings" and garner enough support, but PP in large part is treated as an addition to rather than an integral part of the planning process (N. Ploos van Amstel, personal communication, February 2021).

3.1.2 Technical/Engineered Approaches

The Delta Commission ultimately designed the Delta Plan, which was a series of 13 Delta Works, or features, that would shorten the coastline and protect the Netherland's southwestern delta from damage at a level similar to 1953. The locations of these features are depicted by the lines in Figure 3. Two of the most notable feats of engineering are the Oosterscheldekering (Eastern Scheldt storm surge barrier) and the Maeslantkering (Maeslant storm surge barrier).

The Oosterscheldekering is a three-kilometer-long dam containing sluice gates that keep the water flowing naturally between the open ocean and the bay being protected. It was the largest of the Delta Works projects and cost 2.5 billion Euros. The 65 pillars were constructed in a pit on a manmade island, so that when they were complete, the pit could be flooded and pillars put into place. The pillars are hollow, so once in place they are sunk/filled with water and then sand, followed by stone around their bases. A road spans the dam and the sluice gates are able to be closed when sea level is projected to rise three meters during a storm event (Watersnood, 2018). Similar structures to the pillars, called caissons, are often used to create and/or reinforce dikes on a smaller scale.

The Maeslantkering in Figure 4 is a pair of gates that can close to protect the city of Rotterdam from any threat of flooding. They are each the size of an Eiffel Tower on its side, with a barrier 72 feet tall and 689 feet wide. They move/operate using a ball joint that is 38 feet in diameter. When the gates close, they fill with water and sink down to a concrete base on the riverbed, virtually sealing off any inflow from a storm surge.

Figure 4: Maeslantkering in Rotterdam (ANP, 2018)

All 13 Delta Works projects are said to be able to protect against a 10,000-year storm. The majority of the other projects were smaller dams or dike reinforcements, which are categorized as hard infrastructure (meant to protect against water intrusion/inundation). In 2007, the Dutch government started the Room for the River Program: efforts to restore the natural floodplains of four major rivers that flow through the Netherlands. In more than thirty locations, levees were relocated, channels were deepened, floodplains were lowered, side channels and flood bypasses were created, and residents were asked to move further from the rivers. This is a soft (or passive) infrastructure approach to flooding, as the goal of the program was not to prevent water from entering areas, rather to allow it to flow naturally into areas where damage would be least harmful (Rijkswaterstaat, n.d.).

It is also important to look at projects at varying scales, as nationwide initiatives like the Delta Works are introduced at a federal level and require significant funding. City-wide and community-wide initiatives may be better indicators of what could be translatable in Boston. For example, the people of Rotterdam work to uphold their well-known profile as water management experts, which is one motivating factor for continuing to enhance the city's adaptability. Projects that expand public green space and increase open water such as water plazas, floating buildings, and multi-purpose dikes reinforce this profile and provide more than just the singular benefit of preparing for increased flood risks.

3.2 China

China is the largest carbon emitter in the world as a result of their largely industrial economy. International attention has caused the Chinese government to shift their focus to green energy to maintain a good image on the global stage. Climate change policy has focused more on reduced carbon emissions and switched to renewable energy sources than addressing other challenges related to the environment (like sea level rise). Reducing carbon emissions will have benefits nationally and internationally in the long term. In the short term, however, sea level rise is a challenge that needs to be addressed to prepare the country for the impacts of climate change. Shanghai, Guangzhou, Tianjin, Ningbo, and Qingdao are five "coastal megacities" in China that are projected to be the most severely affected by sea level rise in the near future. The projected population affected in China could be the highest out of all the countries in the world, due to the high growth rates and population densities of these cities (Hanson, et al., 2010).

3.2.1 Government Policy and Citizen Involvement

The Chinese government is authoritarian, which does not leave much space for citizen involvement throughout the policymaking process. Regardless of who the stakeholders are or what they want, the government makes its decisions from top down. What these decisions are depends on the goal at the time, which since the 1990s has been strong economic growth on the East Coast, and now economic growth in Western China as well as movement towards green energy. Furthermore, there is a very strong relationship between engineering and the

government in China, and it is the primary approach to solving big challenges, even those of a social nature.

As a result of this unique set of relations between state and society, opportunities for public participation are limited to certain topics and avenues. Policy entrepreneurship is one way in which cities or municipalities can have a say in what happens locally. When a policy is passed, the work of enforcing it or carrying it out falls on the decentralized powers (municipal, provincial governments). They have the ability to interpret the policy/legislation so that it fits better with the goals of the town/city/province. Citizen activism is gradually becoming more common when policies arise related to pollution/air quality and other environmental issues, for example. However, the central government remains the dominant authority on policies, initiatives, and projects that happen all over China. There is an intricate hierarchy in which a person's amount of power and types of relationships determine whether something gets done.

Such a system means the government takes a more activist role in solving problems than private and non-governmental organizations. The central government takes full responsibility for addressing issues that arise because of its top-down structure. The communist rhetoric is about equality, but large disparities remain between the rich and the poor, accompanied by a huge middle class. Federal funding is distributed in a way that treats some cities as separate states, meaning they are large and important enough to receive as much or more funding than another province in China. It would be like New York City or Boston having the same funding opportunities as any state in the USA. In this way, the goals of the Chinese government, such as preserving its image as a well-respected country, dictate for what and where funds are allocated (J. Rudolph, personal communication, February 2021).

3.2.2 Technical/Engineered Approaches

To no surprise, China has taken rather straightforward and technical approaches to addressing sea level rise and coastal flooding. The exponential growth of China's coastal cities has caused massive amounts of impermeable surfaces and added stresses to wastewater and stormwater collection systems. More frequent and severe storms have resulted in costly flood damage in urban areas.

In 2014, the "Sponge City Concept" (SCC) was initiated by the Chinese government in response to the flooding. The idea of a "sponge city" is one that is able to absorb runoff by slowing the water through permeable surfaces and storage. The concept also includes purification and reuse of that water, and eventual and controlled discharge. Rather than building infrastructure that will help water exit the city as fast as possible, this concept takes a softer approach by working with the water as a beneficial resource rather than a negative event.

The idea did not originate in China, however, having been used in varying capacities in Vietnam and India, and even on a smaller scale in the Netherlands. China's goal by 2020 was to have 20% of the urban area to absorb, retain, and reuse 70% of rainwater. By 2030, the

goal is to have 80% of the urban area meet this goal. The projects through which they plan to achieve this are less concrete, as any cities involved are still in the pilot phase of the initiative. Much of the planning has been left up to the respective cities. Projects that have already been completed include installation of underground water storage units, artificial wetlands, grass ditches, rooftop gardens, permeable sidewalks, and rainwater collection systems for reuse (Yingzi, Yi, & Xiaomin, 2020).

The China Europe Water Platform (CEWP) is a collaboration that exists to increase the dialogue around water policy, research, and development between participating members in the European Union (EU) and China. Funding for the SCC has been hard to come by, so it makes sense to enter into jointly funded partnerships such as the CEWP. In this way, multiple countries can collaborate and learn from each other about what does and does not work, and what is the smartest way to move forward without hindering economic growth (CEWP, n.d.).

3.3 Additional Case Studies

Acknowledging that the Netherlands and China are not the only countries to take innovative approaches to sea level rise, several other projects are worth noting in areas where the threat is very real. Not every project is as successful as the Delta Works or proceeds as smoothly as the introduction of the Sponge City Concept. Russia's St. Peterburg Dam and Venice's MOSE Barrier are examples of projects that have met more challenges than anticipated in their planning and construction.

Saint Petersburg, Russia, sits at the mouth of the Neva River which flows into the Baltic Sea, and has suffered several devastating floods in its history. Having been the historic capital of Russia from 1712 to 1918, people recognized early that the low-lying city needed to be protected from storm surges coming into the Neva Bay. Planning and construction of a flood protection system in the Soviet Union did not begin until around 1979, however, and later came to a halt around 1989 when the Iron Curtain fell. The project was largely abandoned (besides limited maintenance of completed works) until around 2002. There were concerns over funding as well as the pollution levels in Neva Bay and whether the construction was a cause of environmental impacts. Only after European banks stepped in to help with feasibility studies and funding for project completion was the barrier finished in 2011. It was not finished without challenges along the way, as ten companies from various countries, cultures, and areas of expertise had to learn how to collaborate to make sure all the complex parts functioned correctly. Construction was also urged along in the early years of Vladimir Putin's presidency, as he had attended Saint Petersburg University and wanted to see the barrier finished ahead of schedule.

Another aspect that incentivized its completion was the importance of finishing Saint Petersburg's outer ring road, 1,961 meters of which is an underground tunnel to allow for ship passage above. The flood protection system itself is composed of 11 rock and earthen embankment dams, 6 sluice gates to allow for water flow, two navigation channels for ships, and the road and associated infrastructure running along and under the other components. The

whole system stretches about 25 kilometers, closing in Neva Bay and ideally protecting it from a 10,000-year flood. Upon completion in 2011, the project was estimated to cost a total of $3.85 billion (Hunter, 2012, CH2MHILL, 2013). Figure 5 provides an overview of the project.

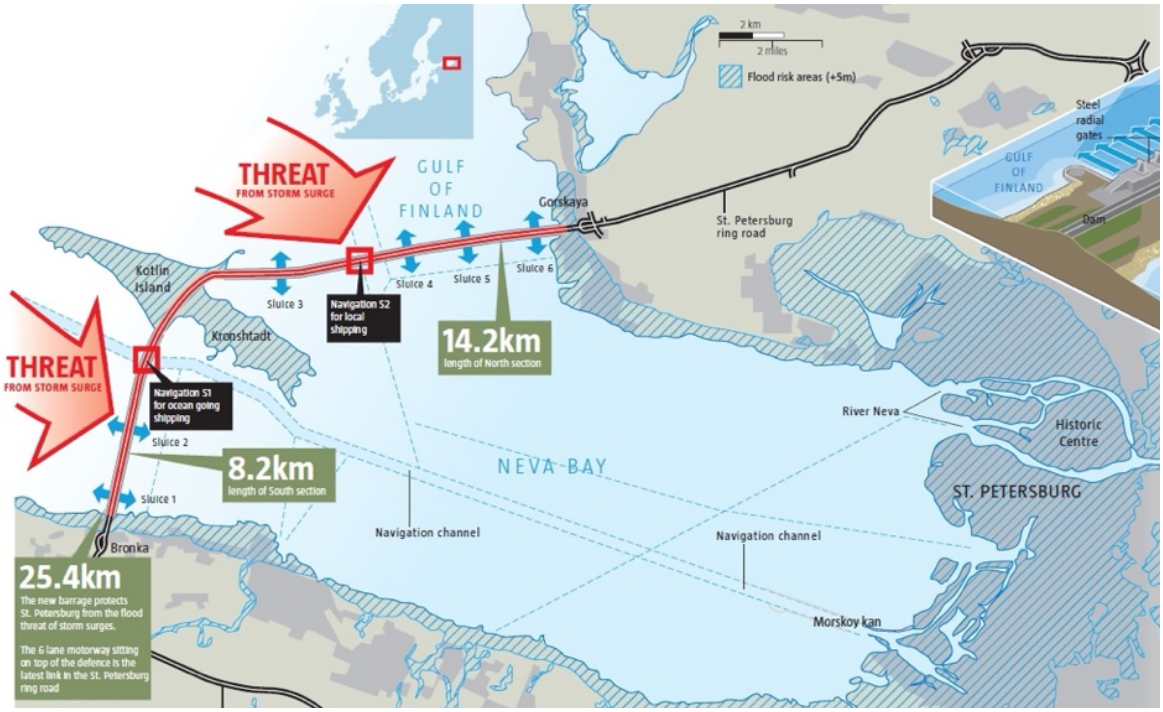

Figure 5: Overview of the Saint Petersburg Flood Barrier (Editor, 2009)

In Venice, MOSE stands for Modulo Sperimentale Elettromeccanico, and is an allusion to the Bible story of Moses parting the Red Sea. MOSE is a mobile storm surge barrier that is only used when forecasts project high enough storm surge or tidal levels. Instead of being well-known as an ingenious and successful engineering feat, mention of the barrier evokes feelings of controversy. After a disastrous flood in the city of Venice in 1966, it has taken more than 50 years to plan, approve, and construct the barrier. Construction started around 2002 and was projected to be finished in 2011; however cost overruns and corruption among high ranking officials involved in the project hindered its progress substantially (Goodell, 2017).

The project consists of barriers installed in three locations along the perimeter of the Venetian lagoon. The design involves rows of hollow steel gates which lay on the ocean floor attached by hinges. When the threat of flooding arises, water is pumped out of the gates and replaced by air which causes them to float three meters above the surface. Failure of the system to rise soon enough to prevent knee-high flooding in Venice has already been recorded in December 2020 (Goodell, 2017). Furthermore, concerns have been expressed over the long-term environmental impact of MOSE on the lagoon ecosystem. The project has been plagued by political, environmental, and financial challenges (including a price tag that rose from $2 billion initially to $6 billion and counting) that seem to have caused more alarm than

comfort in a city where the effects of climate change and sea level rise are being felt on a severe level (Umgiesser, 2020).

Resident relocation is also a strategy in international cases that needs to be taken into consideration when looking at lessons learned. Relocation is often regarded as the least desirable and costliest long-term solution to sea level rise, which is why other avenues are pursued first. Relocation is considered only when the threat becomes so imminent or extreme that it is the only option to save a city or community. This option has been pursued in low-lying cities like Jakarta, Indonesia, and many Small Island Development States (SIDS). SIDS experience intensified and frequent flooding, rising sea levels, and land subsidence at higher rates than coastal areas on larger land masses. Saltwater intrusion is taking place where freshwater is over extracted from aquifers underneath cities/countries (Sugar, Kennedy, & Hoornweg, 2013).

Two communities in Fiji that relocated due to climate-related risks are case studies in the lessons learned from such an endeavor. The 153-person village of Vunidogoloa was moved 2km inland at the request of the village headman. It was the most plausible solution to maintaining the community; technical solutions like adapted infrastructure or protective barriers were either too expensive or not possible. The 170-person village of Denimanu was partially relocated after coastal dwellings were destroyed from a cyclone in 2012 and rebuilt on the slope of a hill further away from the coast.

Many more communities in Fiji and other SIDS face the same fate due to lack of resources, both financial and material, to fight the losing battle for their current coastal land. Some SIDS and island communities have even resorted to buying tracts of land in other countries, like people from Kiribati moving to Fiji and Alaskan villages relocating to the mainland (Jarvis, 2010).

Outcomes from Fiji's relocation projects produced more positive than negative outcomes, improving water and food security, safety, community cohesion, housing, and facilities among others (Piggott-McKellar, et al., 2019). Yet community members said that they felt a lack of involvement in decision-making throughout the planning process, and were informed only after decisions had been made. Once again, public participation was seen as an addition to, rather than an essential part of, the planning process.

The importance of public participation is one takeaway that needs to be prioritized in future relocation efforts so that perspectives from a wide range of people can help maximize the quality and effectiveness of relocation. Additionally, relocation presents an opportunity to plan a new community and space that improves upon not only climate-related safety, but also economic, political, social, educational, and health systems. In Vunidogoloa and Denimanu, unforeseen issues arose such as water/drainage/septic system malfunctions and erosion concerns. Relocation plans should include long term involvement and monitoring considerations to address new challenges that may arise. Challenges can be avoided, however, if the initial relocation site selection and planning is thoroughly thought out and the impacted residents are involved.

4.0 Comparison of Case Studies to the United States and Boston

Comparing different countries creates challenges. Some unique qualities must be looked at subjectively and no two countries have the same history or structure. It is important to be mindful of the circumstances and way of life characteristic of each nation and understand that what may work for one could very well fail in another. The differences between government policy and citizen involvement in the Netherlands, China, USA, and Fiji will be considered, followed by the technical and engineered approaches in the respective countries.

4.1 Differences in Government Policy and Citizen Involvement

The most salient difference between the approaches to sea level rise in the Netherlands and the United States is the prominence of the problem in everyday life. The Dutch have realized that unless they move out of mass swaths of land in their country to relocate, they must find a way to protect themselves from or to live with water. The Netherlands also has an international reputation for their success in and attentiveness to water management. For this reason, water-related issues have always been high on the agenda for the Dutch government, as opposed to the US, where priorities diverge between regions or government agencies.

Similarly, the USA and China are at different points in their growth as developed nations, and thus have differing priorities. Whereas the United States' GDP has been growing steadily since the 1950s, economic restructuring in the 1990s in China led to a GDP that is growing at a much higher rate and has now surpassed the USA's (Roser, 2013). Coming a little later to the game but moving at a higher pace, China is the biggest emitter of CO2 but also now the biggest investor in green energy. With a population over four times the size of the US, actions happen at a larger scale in China, which is important to remember as each country transitions to climate resilience and sea level rise adaptation.

The Netherlands federal, provincial, and municipal governments have a prominent framework in place to address challenges related to water, the most notable being the Rijkswaterstaat and the water boards. The United States' coastal counties (which includes Boston) make up 10% of the country's landmass, yet 40% of its population (NOAA, 2019). One would think that water and coastal authorities would play a more prominent role in policymaking in the US if the challenge affects such a large portion of the population. Nationwide efforts and funding towards flood protection projects do not dominate the American agenda as much as the Dutch. This might be a result of the United States' current focus on renewable energy sources and long-term focus on economy rather than climate adaptation.

Moreover, it is not necessarily that the structures are not in place in the United States; rather, regulations and political agendas do not place these issues at the forefront of responsibility and importance. Waterfront construction is a term that does not exist in the Netherlands – building on the beach is not allowed. Flood insurance (NFIP) ensures American homeowners that they will be able to rebuild anything they lose in a natural disaster, but no better than it was before. The big distinction here is proactivity versus reactivity. Henk Ovink

asserts that the American flood insurance program is going bankrupt paying for people to live in the nation's most vulnerable areas. He says "The storms are perhaps man-caused, and you can debate that. But the catastrophes because of the storms? Those are man-made." The United States is spending too much money rebuilding what storms have destroyed (in over 30,000 property cases, an average of five times) (Kuper, 2020). Ovink was the principal actor in inventing and getting the Obama administration to fund the international Rebuild by Design competition after Hurricane Sandy.

Community input on project plans is not always incorporated once the government has made its decision. This is an effective way to accomplish something quickly but can often lead to discontented citizens. In the U.S., the Dutch-designed project receiving $230 million of those funds was controversial. Residents expressed concerns, and plans were eventually amended, and construction moved forward. In the Netherlands and even more so China, this rarely happens.

Government reaction time after natural disasters, however, is not always a function of how well a city or area bounces back. In the case of Venice, it took over 50 years to decide on a project plan, yet the result still played out quite poorly. Within six years after the 1953 flood, the first Delta Works project was completed in the Netherlands, and the 13th and final project 45 years post-flood. The Netherlands has already reaped the benefits of these protections. The Saint Petersburg barrier took about 32 years. The difficulty with timelines like these is that by the time the project is planned, adopted, and constructed, climate change effects could very well have worsened, and the design needs to be updated. This is one of the biggest problems that US coastal cities are running into when trying to take action.

Before the uncertainty of what is the best design and where to put it is uncertainty about who is in charge of addressing these issues in the first place. If one country chooses to take drastic measures to reduce their carbon emissions, yet others don't do the same, that one country would be hurting its economy and barely making a dent in the mitigation of climate change. So, why should the Netherlands spend so much money trying to reduce their carbon emissions when they only account for less than half a percent of all carbon emissions in the world (Ritchie, Roser, 2020)? And likewise, for even smaller countries like SIDS?

Like the effects of carbon emissions, sea level rise knows no borders and must be addressed regardless of whether the causes are local or global. This begs the question, why haven't countries with coastal megacities worth billions of dollars in assets spent more time trying to protect them? In China, the government takes full responsibility for addressing national concerns. The Sponge City Concept was not a result of a competition designed for private businesses and investment. There is a respect for civil service and government in China that the US does not have. Where the smartest engineers and businessmen are most likely part of private enterprise in the US, the opposite is true in China. There is more involvement of businesses and non-governmental organizations in addressing issues related to climate change in the United States than in the Netherlands or China. Design and construction

standards in the US are less stringent to allow for more economic growth and freedom. How each country has fared as a result of these differences in policy and action is up for debate.

4.3 Technical/Engineered Approaches

If only hard infrastructure approaches to sea level rise protection are taken into consideration, the Netherlands arguably has the most experience and expertise. This is evident in the fact that Henk Ovink advises 35 different countries and many US cities. Naturally, government policy overlaps a great deal into the kinds of technical steps/approaches taken.

In China's case, they take an engineered approach to almost all the challenges the country faces, even social issues, to their benefit or detriment. China is on the forefront of engineered systems as well, being home to the largest hydroelectric gravity dam in the world (Three Gorges Dam). With a shift in focus to resilient coastal cities and protection against climate change, China could soon become more renowned than the Netherlands for technological advances in sea level rise protection.

A study comparing the flood resilience of New York City and Shanghai revealed that Shanghai is at much greater risk for flooding but it is also better prepared to protect itself from extreme events than New York. The study also suggested that past disasters in Shanghai have had a stronger influence on follow-up policy and action than in New York, as the US city has only experienced moderate impacts from natural disasters before Hurricane Sandy. However, both cities appear reluctant to overspend on actions or projects that are irreversible. For this reason, substantial implementation of flood protection measures following a storm (following a "focusing event", something that reminds policymakers and public of the importance of protecting the city and preparing for future threats) often becomes dragged out and loses support as memory of the event decays over time (Xian, et al., 2018).

As a solution to the pressure of near-immediate post-disaster project implementation, a few approaches have worked. For the Netherlands after 1953, this meant promptly setting up the Delta Commission and passing the Delta Act in 1959. Unanimous approval and a strong sense of government responsibility over the nation's coasts and citizens' safety was needed for this to happen. In the US, the question of "Who's job is it?" slows this process. In China, government control over the nation's coasts and citizens exists, but whether it is a priority is another issue.

Looking at the way sea level rise adaptation has evolved over the years, a common thread runs through the technical concepts of policies and plans being made around the world. The Room for the River program, the Sponge City Concept, and the Resilient by Design competition all have a **shifted focus from "against" to "with"**: working with the flow of the water rather than fighting it. Accommodating the water by providing it space to be stored, to move, to seep into, and to be reused for beneficial purposes. Strategies are moving towards adaptable designs that account for future changes in climate projections. There is consensus that the climate is always changing, and the general understanding is that by changing, we mean intensifying. Water levels will fluctuate, temperatures will change, and natural disasters

will occur, all with increased severity and frequency. Project designs can quickly become obsolete, a near future the MOSE barrier may be facing after billions of dollars of investment. Dynamic adaptation measures will be essential for any future coastal resiliency projects.

4.4 Additional Considerations for Boston

At a local scale, Boston can learn from the different approaches taken by cities and towns like New Orleans, Rotterdam, and Saint Petersburg. Harbor-wide barriers have already been studied as an option for Boston and appear to be less cost effective than shoreline approaches. However, this choice of shoreline protections over grand, sweeping projects might be an indication of the resistance to the understanding that things may get a lot worse a lot faster than the projections say. The shoreline protections that New Orleans was known for did not fare so well in Hurricane Katrina. The rejection of a harbor-wide barrier for Boston like the scale of Saint Petersburg's or Rotterdam's may be based in sound scientific data and reasoning, but the caveat is that things are changing faster. A choice may soon have to be made between the health of the harbor ecosystem or the safety of Boston's residents.

The other option, however, manifested in Fijian communities, is relocation. The US and Boston have largely avoided relocation for multiple reasons. First, the threat is not seen as severe enough to need to abandon coastal land to the sea yet. Second, design and construction standards are not easy to dramatically change at the drop of a pin, and the real estate market would suffer. The structure of the NFIP and FEMA would need to be overhauled for relocation to be considered a better economic choice for property owners. The reason relocation worked for the Fijian towns of Denimanu and Vunidogoloa was because of the absence and extremity of measures needed for adapting and protecting the coastal villages where they originally stood. In this case, it would have cost more money and been less effective to decide to stay put and try to protect their communities. One interesting outcome to consider, however, is the number of benefits to living conditions, services, and overall livelihood the communities received after relocating. It is worth looking into how [partial] relocation from vulnerable areas on Boston's coast might improve the quality of life of those being relocated, and the economic viability of the option.

5.0 Recommendations and Conclusion

Boston is ahead of the curve compared to the rest of the United States in preparing for a climate resilient city. In order to set an example for other less prepared US cities, Boston should look to the international cities setting an example, like Rotterdam. The population of Rotterdam is about 623,000, and Boston's is 684,000. Boston's total GDP is at least twice that of Rotterdam, so one would think the city would be able to allocate more funds towards climate resilience (FRED, 2018; City of Rotterdam, 2009). Although Rotterdam is motivated by wanting to uphold its national reputation of water expertise, so Boston can earn its own reputation of climate action and resilience.

Policies and plans will need to be initiated by the city of Boston, as opposed to receiving national funds for flood protection at the level of the Maeslantkering like Rotterdam. It is not realistic for the United States federal government to allocate as much funding and attention to Boston as the Netherlands did to Rotterdam, because the US contains so many other coastal megacities more at risk of flooding and climate threats. This unfortunate reality means Boston must take matters into its own hands, such as the Climate Ready Boston initiative.

Outlined below are the major recommendations for the City of Boston as a result of research about and comparisons between other international cities and countries.

- Educate lawmakers and authority figures about the imminence of climate threats on Boston and the benefits that result from prioritizing resiliency policies and actions.
- Design shoreline protections to be adaptable to new climate projections.
- Design adaptation strategies to be multi-purpose. In order to garner enough support from authorities, citizens, and businesses, the strategy needs to provide more than one environmental, social, or economic benefit.
- Adapt coastal construction and design standards, policies, and regulations to better reflect climate projections and the associated risks to property.
- Plan for the prompt implementation of resiliency measures post-disaster in order to benefit from the mindset around "focusing events."
- Involve citizens in the research and planning process of a project rather than simply informing after the fact. Mechanisms that help residents take ownership over a project will ensure that needs have been met to the best of everyone's ability.
- Continue to increase funding and research going towards climate adaptation and pilot projects. Planning and replanning will not result in as much as planning and testing out.

Boston already has a head start on a few of these recommendations, such as making shoreline protections adaptable to new climate projections. Energy to push these initiatives forward will need to come from not only the citizens of Boston but largely the people in power creating policies and regulations. These recommendations are based on the research presented in this report. The research in this report, however, only accounts for a fraction of what is available. Further case studies and research should be developed to investigate what

has and hasn't worked in coastal climate adaptations. Therefore, this is far from an exhaustive list, but a push in the right direction.

Climate change is hitting at differing intensities; it knows no boundaries and a country that may contribute very little to the causes could feel the most severe effects. Whether the rate of adaptation is enough to match or overcome the effects felt is dependent on the multitude of factors previously discussed that contribute to successfully living with the environment. Hindsight is 20/20 but as hard as society tries, the future is impossible to predict perfectly. Cities face dilemmas of priority and timing – will they choose short-term options of defense or long-term options of relocation? Will the United States restructure the National Flood Insurance Policy to help society realize risks involved with building near water?

After seeing many of the world's largest and most powerful countries implement major storm surge barriers, it is hard to believe that the US has not made more of an effort to build this type of protective infrastructure as well. On the other hand, research may be turning away from large barriers and towards smaller shoreline protections. Will smaller-scale efforts still protect millions of dollars in infrastructure while adapting to a changing climate?

Boston will grapple with all these challenges and more. The natural world has adapted for centuries to whatever environmental changes are taking place and will continue to do so whether these changes are caused by humans or not. The bigger question is what humans can do to live sustainably with all that the natural world has to offer amid rising sea levels.

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