SEA LEVEL RISE: PREPARING FOR AN UNCERTAIN FUTURE

Background Information

Museum of Science

Northeastern

Arizona State University

ECAST
EXPERT AND CITIZEN ASSESSMENT OF SCIENCE AND TECHNOLOGY

Section 1: Introduction to Resilience Planning

Engineers, farmers, business owners, and other community stakeholders have dealt with the impacts of weather and climate related events for centuries. Communities around the world are thinking about how to become more prepared and resilient to hazards such as sea level rise, extreme precipitation, heat waves, and droughts in a changing and uncertain future world. Increasing population and land use, combined with a changing climate, make these kinds of hazards increasingly relevant to civic planning. Most urban and regional planners are now conducting studies of their cities to identify threats to economic, environmental, and social development from weather and climate related hazards.

An increasing number of city planners are creating local "resilience plans," which go beyond identifying vulnerabilities to also assess the potential benefits, costs, and tradeoffs of a range of proposed resilience strategies. For example, New York City recently issued a report called "One New York: The Plan for a Strong and Just City," which states that "a changing climate, a growing population, aging infrastructure, and an evolving economy with increasing inequality pose challenges to our city's success and quality of life. Recognizing that we determine New York's future by how we shape our response to these challenges, our work includes actions to mitigate climate change while also preparing for the risks it presents, ensuring quality of life for generations of New Yorkers to come." [1] A few examples of actions outlined in the plan include: transforming buildings to be more flood-resistant, preparing neighborhoods across the city for better emergency management, and increasing the number of trees in the city to increase resilience against urban heat waves.

This packet provides basic information about an array of resilience strategies for dealing with the hazards of extreme precipitation and sea level rise. This information is provided to help you feel comfortable discussing elements of resilience planning for these hazards, which are faced by many communities. We will not be testing you on this information, but instead making sure everyone at your table has the same amount of information at the beginning of the event. The US National Oceanographic and Atmospheric Administration (NOAA)'s "US Climate Resilience Toolkit" is a valuable resource that helps planners think about actions that cities can take. At the upcoming forum, you and your fellow participants will follow the same steps that these resilience planners use to prepare their communities for weather and climate related hazards.

[1] OneNYC report, online at https://onenyc.cityofnewyork.us/visions/resilience.

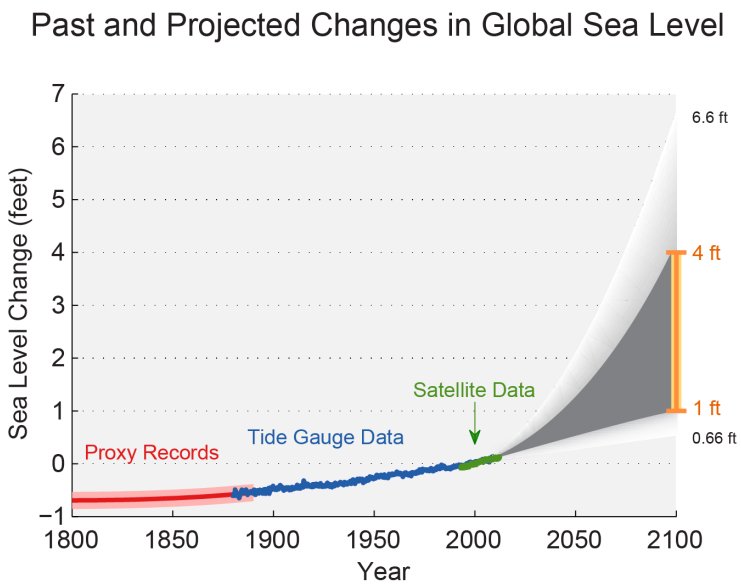
Your group will learn about the vulnerabilities to a community, consider the tradeoffs of several possible resilience strategies that could help the community to adapt, and then create a resilience plan by thinking about the impacts, opportunities, and challenges that these kinds of strategies will present for different kinds of stakeholders. We hope you will learn about the difficult and complex decisions that face resilience planners in communities around our nation and our world.

The Five Steps to Resilience.
Source: NOAA Climate Resilience Toolkit.

Section 4: Vulnerabilities to Sea Level Rise

Sea Level Rise Overview

Global sea levels are rising, and scientists predict that they will continue to rise at an accelerated rate over the next several hundred years. Higher sea levels in the coming decades present a number of hazards for coastal communities, and resilience planners are thinking about how to protect residents, infrastructure, and ecosystems from the worst impacts. Sea level rise increases the risk to coastal communities of regular tidal flooding, and also means increased vulnerability from events such as storm surges from hurricanes or increased coastal erosion.



Past and Projected Changes in Global Sea Level Rise. Source: US National Climate Assessment 2014.

Why are sea levels rising?

Sea levels change for three primary reasons. The first reason is the **thermal expansion of the oceans.** Like mercury in a thermometer, the volume of liquid water gets bigger as its temperature increases. The ocean absorbs about 90% of the heat from human-caused emissions, and so the level of the oceans has risen consistently over the last century (approximately 8 inches globally since the 1880s) in response to the warming the planet has experienced during that time.

Sea levels also rise as **ice from the land** enters or melts into the ocean. Just as dropping an ice cube into a near-full glass of water causes the liquid to spill over, additional ice shelves or glaciers that slip into the ocean will push the level of the sea surface upward. The vast majority

of glaciers and ice shelves around the world are melting rapidly. As this ice melts on the land, the resulting meltwater flows into the ocean, adding to the amount of liquid in the sea.

Sea levels also are rising relative to coastal communities in many locations, because the coastal land is sinking. When people extract or redirect streams of groundwater, store water on land in reservoirs, or pull natural gas or other materials from the deep ground, the surrounding land often changes position in response. This process, known as **subsidence,** results in a lower land level relative to the height of the ocean.[23]

How much will sea levels rise in the future?

Scientists are very confident that sea levels will continue to rise in cities around the world, and the rate of increase is very likely to accelerate over the next 50-100 years[24], but it's not possible to predict the exact amount that sea levels will rise over that time. This is both because it is difficult to predict how much warming will occur due to human-caused and natural effects, and also because we don't understand everything about the climate system. For example, scientists' predictions about the rate of melting ice sheets in places like Greenland or Antarctica may be overly conservative. The US National Climate Assessment advises that a reasonable low end for resilience planning is around 1 foot of average sea level rise by 2100, while 4 feet is a plausible high end for planning over that time. Sea levels will not rise uniformly everywhere; some places will experience more sea level rise than others due to factors such as changes in ocean currents, movement of heat within the oceans, and geologic changes and subsidence. Also, sea levels will not stop rising in 2100; the rise will continue for much longer even if human emissions stopped today.

Sea levels will continue to rise and accelerate in around the world, so resilience planners around the country are thinking about how coastal communities can become more flexible, adaptable, and prepared for future sea level rise, in an effort to protect residents, infrastructures, and coastal ecosystems. While the direct impacts will be felt by coastal communities, sea level rise will also have more far-reaching impacts on transportation hubs and international commerce. Some impacts of sea level rise will be experienced by everyone.

The following section outlines some of the social, economic, and environmental impacts that sea level rise, combined with storm surges, can have upon urban coastal communities. This will introduce you to some of the problems and opportunities that public officials face when considering and designing resilience plans for their regions.

Social Impacts

164 million Americans live near a coastline, and nearly 5 million residents in the United States live within 4 feet of the local high-tide level. Coastal residents, businesses, and infrastructures

[23] http://www.climatecentral.org/news/sinking-atlantic-coastline-meets-rapidly-rising-seas-20247
[24] https://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf

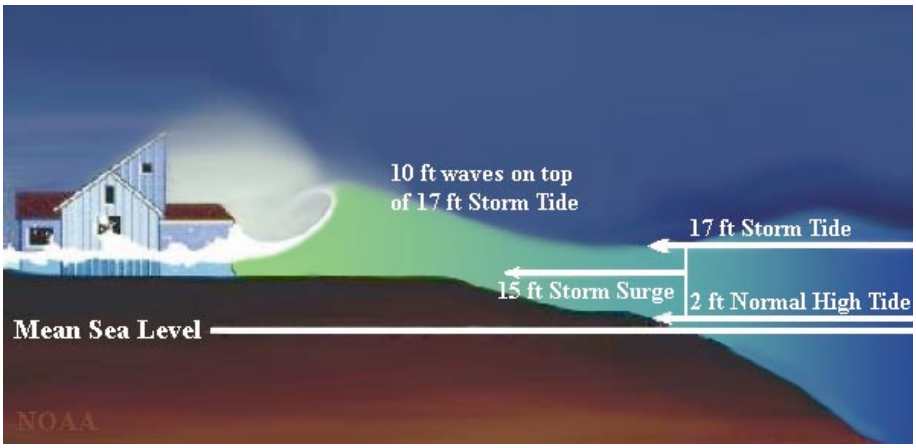
in these densely populated communities are likely to be impacted or physically displaced by rising sea levels. The US National Climate Assessment reports that "Coastal lifelines, such as water supply and energy infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, erosion, and other climate-related changes."[25]

Some "sunny day" or nuisance flooding occurs at high tide, even when there are no precipitation or strong wind events. These floods may be only a foot or two deep, but can cause roadways to be impassable, flood basements in low-lying areas with saltwater, or negatively impact coastal ecosystems.

Researchers from NOAA have shown that the frequency of these "sunny day" floods has increased dramatically across the Eastern and Gulf coastlines in the last half-century or so as sea levels have risen[26]. In Baltimore, for example, the average number of observed days of nuisance floods has gone from about 1 to about 13 days per year over the 50-year period between the late 1950's and the period between 2007-2013[27].

"Sunny day" tidal flooding in Charleston, SC. Image: The New York Times.

[25] US National Climate Assessment (2014). Online at http://nca2014.globalchange.gov/report.
[26] Sweet and Park (2014) "From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise." *Earth's Future.* Online at http://onlinelibrary.wiley.com/doi/10.1002/2014EF000272/full.
[27] Sweet, W., J. Park, J. Marra, C. Zervas, and S. Gill, 2014: Sea Level Rise and Nuisance Flood Frequency Changes around the United States. NOAA Technical Report NOS CO-OPS 073. 58 pp.



Depiction of a storm surge event on top of normal high tide event. Image: NOAA.

Storm surges and extreme precipitation events on top of sea level rise make coastal flooding concerns much more severe. When coastal storms push many feet of seawater towards the shore, the resulting storm tides can overtop structures and protections that were constructed over a century ago when the level of the sea was not as high as it is today. When storm events occur at times when astronomical tides are already high, as occurred in 2012's Superstorm Sandy in the mid-Atlantic, storm surges push huge amounts of ocean water into coastal communities. Storm surge greatly increases communities' risks of physical damage, loss of life, or of potential loss of power and communication from coastal flooding.

Coastal storm surges frequently separate community resources, infrastructures, and neighborhoods from one another. This can isolate vulnerable populations, make transportation impossible, and disrupt emergency services such as the delivery of food, water, or other kinds of essential materials. All of these impacts – loss of power, disruption to emergency response systems, flooding of roadways, flooding of structures, loss of life, and the loss of social connection - were all major problems during events such as Superstorm Sandy and Hurricane Katrina in New Orleans. Another dimension is that economically or socially disadvantaged populations in coastal areas may be less able to adapt to sea level rise. The US National Climate Assessment states that "Socioeconomic disparities create uneven exposures and sensitivities to growing coastal risks and limit adaptation options for some coastal communities, resulting in the displacement of the most vulnerable people from coastal areas."

Economic Impacts

Sea level rise will mean a range of negative economic impacts for many coastal communities, and for society more broadly. The US National Climate Assessment states that "Nationally important assets, such as ports, tourism, and fishing sites, in already-vulnerable coastal locations, are increasingly exposed to sea level rise and related hazards. This threatens to disrupt economic activity within coastal areas and the regions they serve and results in significant costs from protecting or moving these assets." Interruption to business activities,

damages to buildings and structures, impacts upon coastal recreation and tourism, and the costs of displacement and relocation of community resources can cost hundreds of millions of dollars or more. Further, disruption to transportation hubs can threaten national or global commerce and have impacts thousands of miles away from coastal communities. For example, the National Climate Assessment identified 12 of the nation's largest airports (including all three of the major airports serving New York City) that have at least one runway with an elevation within 12 feet of current sea levels. These locations are vulnerable to large storm surges now and the vulnerability will increase as sea level rises over the coming decades.

Environmental Impacts

Sea level rise and associated storm surges also pose hazards to the local environment and ecosystems. The US National Climate Assessment states that "Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses; climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts." For example, more intense and frequent waves, which result from higher sea levels, will increase erosion of coastal beaches. This threatens the health of coastal organisms directly on the coastline, as well as inland ecosystems that are sheltered by natural beaches and dunes from the barrage of coastal tides and seawater. Additionally, freshwater environments do not tolerate the addition of saltwater well. For example, the Charles River Dam that the Museum of Science in Boston sits on protects against a wave height of 12 feet. The city of Cambridge, MA predicts that the dams should be secure until around 2030, but higher tide levels will cause seawater to overtop the dam and enter the freshwater river ecosystem, posing hazards to aquatic organisms in the Charles[28]. When combined with a potential increase in extreme precipitation events, coastal storm surges can worsen negative impacts from runoff, reducing water quality or causing other kinds of environmental problems.

Section 5: Potential Resilience Strategies for Sea Level Rise

Cities will need to plan for some amount of sea level rise in the coming decades, and must consider the tradeoffs of various strategies for resilience without complete certainty as to what will occur. Resilience planners around the world are considering a range of strategies that can help to protect cities from coastal flooding and storm surges due to rising sea levels.

The following section outlines a select number of possible strategies that can be used to help prepare cities for coastal flooding and storm surges from sea level rise. While there are many ways for cities to prepare, this section will give you an overview of some of these options and the social, economic and environmental impacts of each. This information will prepare you to

[28] City of Cambridge *Climate Change Vulnerability Assessment, Part 1* (2015). Online at http://www.cambridgema.gov/CDD/Projects/Climate/~/media/307B044E0EC5492BB92B2D8FA003ED25.ashx.

make your own resilience plan for the city that you and your fellow participants will be considering, based on the discussion you will have with your table on the day of the event about the range of possible resilience strategies and their tradeoffs.

KEEP WATER OUT – Installing engineered barriers or natural flood protections to reduce flooding

One important set of strategies is the design and installation of natural or engineered barriers. These systems can help to keep seawater out of entire coastal communities, or to direct damaging tides away from certain vulnerable locations. These structures can be built by people (including seawalls, revetments, or locks) or humans can enhance natural systems (coastal forests, marshes, or dunes) to help keep water away from locations where flooding presents the greatest threat. A massive example of a physical human-engineered barrier is the Thames Barrier in London.

KEEP WATER OUT

Keep Water Out involves building man-made barriers or using natural flood protection to prevent coastal flooding. This could mean installing a massive lock, erecting seawalls, or restoring wetlands.



ECONOMIC ★★

Barriers are expensive to build and coastal armoring and artificial beaches require costly annual maintenance and regular monitoring. Vegetative methods, such as a living shoreline, are less costly. Massive locks are a possible tourist attraction, although the city will lose money in real estate since some of the extremely valuable coastline will no longer be available for redevelopment.

ENVIRONMENTAL ★★★

Barriers can cause environmental damage by restricting and altering the natural flushing of an estuary. Even small seawalls cut off water from its floodplains, which are often valuable breeding and feeding zones. Wetlands are valuable because they filter pollutants, sequester carbon, and create critical habitats for fish and wildlife.

SOCIAL ★★★½

Barriers protect large vulnerable areas from flooding, saving lives and preventing property damage. Similarly, coastal armoring protects development along coastlines. In addition to their flood protection services, beaches and wetlands provide recreational space for communities.

Read through this box to learn more about the Keep Water Out strategy. You will use this information during your discussions at the forum.

Spanning 520 meters across the River Thames, the barrier protects 125 square km of central London from flooding caused by tidal surges. Barriers like the Thames are very expensive to build (and can take many years to install), but when they are strategically located can be an effective way to protect a large area with only a few barriers. Coastal armoring strategies such as seawalls or rock revetments are smaller than huge structures, and can help to protect sensitive structures or neighborhoods more inexpensively. However, these structures can obstruct coastline views, and also negatively impact marine ecosystems because water and organisms cannot pass through them. A natural-enhanced strategy that is gaining popularity is the use of vegetative solutions or living shorelines, which are frequently called “wetlands”. Examples of wetland protection systems include mud flats,

The Thames Barrier in London. Image: Wikipedia.

marshes, rock shores, sand dunes, or beds of oysters or mussels. Wetlands can help to reduce the wave energy from storm surges, prevent erosion, and act as buffers for coastal flooding. Wetlands require time and space to be effective against sea level rise, but many planners are starting to integrate wetlands as part of their resilience planning.

LIVING WITH WATER – Accommodating rising sea levels through preparations to buildings, infrastructures and city spaces

While the "Keep Water Out" strategies described above prevent sea water from coming onshore, "Living With Water" strategies are designed to reduce hazards caused by coastal flooding that may occur. These strategies can include changes to the design of buildings to make them more resistant to floods, elevating streets or structures to bring them above flood levels, or building places in the city to accommodate floodwaters in ways that will be less damaging. Similarly, subway stations can be constructed so that floodwaters will not enter the transit tunnels, and can also be retrofitted or designed with pumps that will dry out the station more quickly. These kinds of strategies protect individual buildings or structures, but cannot protect entire neighborhoods. Therefore, under-resourced groups may not be as safe from coastal flooding events.

Another "Living With Water" strategy involves elevating entire vulnerable sections of a coastal city. The city of Hamburg, Germany, implemented this idea in its Hafencity neighborhood. Planners raised public roads and bridges to a height of 7.5 meters above sea level. The foundations of buildings in the elevated portion of the city are floodable garages that can hold floodwaters during coastal storm events. This strategy can help to protect entire neighborhoods, but costs hundreds of millions of dollars or more to implement, requires huge changes to the cityscape, and can disrupt communities, residents and businesses during and after construction.

LIVING WITH WATER

Living with Water accommodates rising sea levels by allowing water into city spaces. This means elevating roads and buildings above water levels, waterproofing electrical and transportation infrastructures, and building floating or floodable development.



ECONOMIC ★★½

Floodable development is untested and therefore a risky investment, while flood-proofing structures presents challenges to existing frameworks such as freshwater and electricity. Retrofitting buildings can be expensive but may be a cost effective strategy for new buildings.

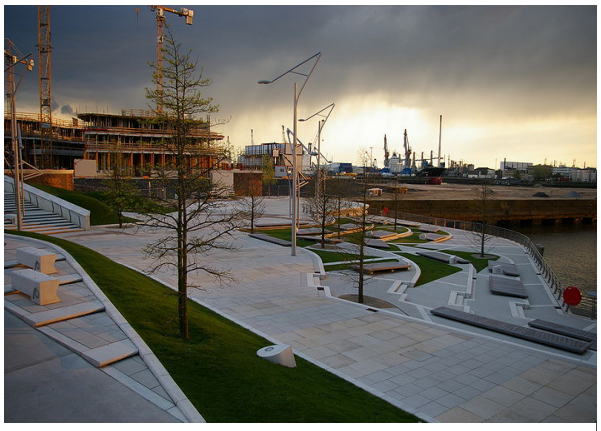
ENVIRONMENTAL ★★★★

Natural areas such as floodable waterfront parks create green space and habitat. Floating structures can provide a dynamic aquatic habitat in a similar way to a coral reef or sunken ship.

SOCIAL ★★

Floodable spaces can be used as recreational areas, although they can also be a public health hazard when filled with polluted stormwater. Floating buildings provide flood and hurricane safety for coastal residents. However, retrofitting and/or closing infrastructure can be an inconvenience.

Read through this box to learn more about the Living with Water strategy. You will use this information during your discussions at the forum.



Elevated promenades in the Hafencity, Hamburg. Image: Wikipedia.

MANAGED RETREAT – Relocate crucial structures or neighborhoods in vulnerable coastal areas

Managed retreat strategies do not reduce the risk of coastal flooding in vulnerable areas, but instead identify structures, regions, or communities that cannot be protected where they are because other kinds of protection are too difficult, and make plans to relocate to safety. Managed retreat plans can safely remove settlements or infrastructures from encroaching coastlines over a period of decades as sea levels rise. This decision can mean abandoning and moving the community completely or relocating elements that have particular vulnerability to coastal flooding (electric grids, water treatment plants, etc.) Pacifica State Beach in California is an example of managed retreat. State authorities determined over a decade ago that they could not keep up with the pace of erosion, and so they bought back coastal properties and enhanced the beach for recreation purposes. This helped to increase flood protection in a community that was experiencing frequent flooding events on roadways and is predicted to be severely impacted by rising sea levels.

MANAGED RETREAT

Drastic managed retreat involves completely relocating vulnerable structures and neighborhoods, while less-intensive measures include prohibiting development in vulnerable zones and offering incentives for residents and businesses to relocate on their own.

ECONOMIC ★★★

Relocating is costly in areas that are significantly developed, but usually less expensive than armoring strategies. The federal government would save money in the long run by reducing losses that they would have to pay for under the National Flood Insurance Program.

ENVIRONMENTAL ★★★★½

Managed retreat can be designed to allow the restoration of flood-buffering wetlands and natural shoreline habitat.

SOCIAL ★★

Important landmarks and attractions can be lost in the relocation process, which can disrupt personal roots to a place. There are also significant political complications involving tremendous legal and equity issues with land and property disputes. Despite this, retreat minimizes human suffering by relocating before a catastrophic flood.

Read through this box to learn more about the Managed Retreat strategy. You will use this information during your discussions at the forum.

Managed retreat options can be coupled with buy-back programs or incentives to compensate owners for the economic and social costs of having to move. The social and economic impacts to communities can be very negative, but may be required in some areas if protections or resources cannot keep up. Some managed retreat strategies allow for increased use of natural areas. For example, formerly inhabited zones or structures can be replaced by floodable plazas, living shorelines or parks.

With this information, you are now prepared to think about how to build a resilience plan for sea level rise based on the social, economic, and environmental impacts of the strategies you choose. On the day of the Forum, you and your fellow participants will use this knowledge to discuss how stakeholders will be affected by your choices, visualize what happens to the city when you they are implemented, and make changes based on your results.

Section 6: Participant Role and Preparation for the Event

The forum you are participating in will be used in eight science museums across the country. Each museum will recruit participants with a wide array of demographics, values, and ideas to create a space that reflects who the people are that live in the region and will be affected by the climate hazards being discussed.

As a participant in this forum, you will be asked to share your opinions, discuss your ideas, and collaborate with your table to make a resilience plan for the city. The first two sessions of the day will involve a fictional city that is grappling with creating a climate resilience plan for one of the hazards you will be discussing. Each fictional city is based on a real place that is currently thinking about ways to become more resilient against the chosen hazard. We chose to use fictional cities in order to create a replicable and unbiased program that can be used in many places around the country and remain relevant to the people who live there. During the last session of the day, you will be able to discuss a topic that is important to city planners who live in your region. This will allow you and your table to think of ideas and options for a resilience planning process that affects your region, and then relay that information to local planners.