BEYOND BARRIERS TO IMPLEMENTATION

A Water Sector Perspective on Sea Level Rise Adaptation

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Water Utility Climate Alliance

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Beyond Barriers to Implementation:
A Water Sector Perspective on Sea Beyond Barriers to Implementation: A Water Sector Perspective on Sea Level Rise Adaptation

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ACRONYMS AND TERMINOLOGY

The terminology and acronyms used throughout this guide are defined below based on the years of collective adaptation experience of WUCA. This comprehensive understanding is based on the following:

- Shared and individual adaptation project experience at WUCA utilities
- Extensive literature and adaptation case study review
- Knowledge-sharing between WUCA members and other water sector colleagues (e.g., WUCA Annual Meetings and WUCA's Climate Resilience trainings)
- External partnerships with adaptation scientists, planners, engineers, and water sector practitioners

Acronyms and Abbreviations

BFE	Base Flood Elevation
BIPOC	Black, Indigenous, and People of Color
BRIC	Building Resilience Infrastructure and Communities
CIP	Capital Improvement Plan
DAPP	Dynamic Adaptation Policy Pathways
EPA	United States Environmental Protection Agency
FEMA	Federal Emergency Management Agency
IPCC	Intergovernmental Panel on Climate Change
JBA	Joint Benefits Authority
LEED	Leadership in Energy and Environmental Design
NOAA	United States National Oceanic and Atmospheric Administration
RO	Reverse Osmosis
USACE	United States Army Corps of Engineers
WUCA	Water Utility Climate Alliance

Terminology

100-year Floodplain/100-year Flood Event – Coastal areas with a 1 percent annual chance of flooding.

(Developed from Federal Emergency Management Agency)

Adaptation – Efforts to avoid, minimize, adapt to, and/or recover from the effects of climate change.

(Developed from Environmental Protection Agency)

Adaptation Pathway – Actions that can be implemented progressively, depending on how the future unfolds and knowledge develops.

(Developed from Werners et al. 2021)

Adaptive Risk Management – The iterative process of adaptation wherein decisions need to be implemented, monitored, and adjusted as needed based on practical experience as future conditions are realized.

(Developed from Hochrainer-Stigler et al. 2021)

Base Flood Elevation – The elevation of surface water resulting from a flood that has a 1 percent chance of equaling or exceeding that level in any given year as designated by FEMA.

(Developed from Federal Emergency Management Agency)

Buyout – The government purchase of private property, typically one with an associated risk like flooding, from a willing seller. The government then demolishes existing structures and may prohibit or limit future development, usually allowing the property to naturally revert to open space in perpetuity.

(Developed from Georgetown Managed Retreat Toolkit)

Co-benefits – The positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment.

(Developed from Intergovernmental Panel on Climate Change)

Environmental Justice – A social movement that strives for all communities to experience equal protection from environmental health hazards and equal participation in the decision-making process to have a healthy environment, regardless of race, color, national origin, or income. A movement that seeks to address unfair exposure of marginalized communities to environmental harms and hazards.

(Developed from Environmental Protection Agency)

Equity (Water Equity) – When all communities have access to safe, clean, affordable drinking water and wastewater services; are resilient in the face of floods, droughts, and other climate risks; have a role in decision-making processes related to water management in their communities; and share in the economic, social, and environmental benefits of water systems.

(Developed from U.S. Water Alliance)

Implementation – The process of making something active or effective; putting a decision, plan or project into effect; execution.

(Developed from Oxford Languages)

Impervious Area – An area with a surface that water cannot penetrate. In these areas, precipitation does not seep into the ground, but runs off into storm sewers or local water bodies.

(Developed from United States Geological Survey)

Joint Benefits Authority (JBA) – A tool that allows multiple city agencies to work together, in collaboration with local communities, to finance and deliver transformative resilient infrastructure, and to attract new investment.

(Developed from World Resources Institute)

Leading Practice – Recognizing that adaptation is a nascent field and best practices have yet to be established; leading practices are those endorsed by WUCA member utilities as an emerging practice with tested results and promise. In this guide, leading practices are defined by short statements and supported by examples and resources.

(Developed by Water Utility Climate Alliance)

Living Shoreline – A broad range of techniques for providing shoreline stabilization through the use of ecological, or "soft" approaches, as opposed to hard infrastructure, to accommodate natural coastal processes and reduce shoreline erosion, produce storm protection, and enhance habitat value.

(Developed from Georgetown Managed Retreat Toolkit)

Nature-based Solutions – Sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to promote adaptation and resilience to combat climate change, reduce flood risk, improve water quality, protect coastal property, stabilize shorelines, reduce urban heat, and/or add recreational space.

(Developed from Federal Emergency Management Agency)

Non-Stationarity – Ever-changing; differences in the statistical characteristics (e.g., mean, variance, covariation) of a variable, or in statistical relationships across space or time. In simple terms, what used to be normal is not normal anymore. A stationary time series of historical environmental data has statistical properties or moments (e.g., mean and variance) that do not vary in time. Non-stationarity is the status of a time series whose statistical properties are changing through time (e.g., due to climate change).

(Developed from Rollinson et al. 2021)

Mainstreaming – The process of integrating something into existing processes, structures, and frameworks; making something new start to be considered normal.

(Developed from Cambridge Dictionary)

Managed Retreat (or planned retreat) – The voluntary movement and transition of people, infrastructure, and ecosystems away from vulnerable coastal areas.

(Developed from Georgetown Managed Retreat Toolkit)

Marginalized Community – Groups and communities that experience discrimination and exclusion (social, political, and economic) because of unequal power relationships across economic, political, social, and cultural dimensions.

(Developed from National Collaborating Centre for Determinants of Health)

Mitigation – Reducing climate change. Involves reducing the flow of heat-trapping greenhouse gases in the atmosphere.

(Developed from National Aeronautics and Space Administration)

Public-Private Partnership – A partnership between one or more government agency and private party for providing a public asset or service for which parties share financial, implementation, and/or maintenance responsibilities.
(Developed from Public-Private Partnerships Knowledge Lab)

Resilience – The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance by responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.
(Developed from Intergovernmental Panel on Climate Change)

Risk (Climate Risk) – The potential adverse consequences of a climate-related hazard or of adaptation or mitigation response to such hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services, and infrastructure.
(Developed from Intergovernmental Panel on Climate Change)

Saltwater Intrusion – The encroachment of seawater into fresh groundwater supplies.
(Developed from United States Geological Survey)

Sea wall – A wall or embankment to protect the shore from erosion or to act as a breakwater.
(Developed from Merriam-Webster)

Setback – The required distance a structure must be located behind a baseline.
(Developed from Georgetown Managed Retreat Toolkit)

Shoreline Hardening – Installation of engineered shore structures to stabilize sediment and prevent erosion and/or provide flood protection.
(Developed from Gittman et al. 2016)

Socially Vulnerable – The propensity and predisposition for communities to experience negative effects caused by external stresses on human health. Such stresses include natural or human-caused disasters or disease outbreaks. *(Developed from Centers for Disease Control)*

Storm Surge – The abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. Caused primarily by a storm's winds pushing water onshore.
(Developed from National Oceanic and Atmospheric Administration)

Uncertainty – A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. Uncertainty can be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgement of experts).
(Developed from Intergovernmental Panel on Climate Change)

Useful Life – The number of years an asset is likely to provide benefits and remain in service.
(Developed from Internal Revenue Service)

Vulnerability – The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
(Developed from Intergovernmental Panel on Climate Change)

INTRODUCTION

As the atmosphere warms due to climate change, there is a direct impact on the hydrologic cycle, thus creating unique challenges for the water sector. The effects of sea level rise and other associated coastal changes (e.g., storm surge, erosion, and flooding) have already had a wide range of impacts on coastal communities, and climate change will only exacerbate these challenges in the future. The hardships brought on by climate change are forcing a paradigm shift for decision-making in the water sector as practitioners seek to implement options to avoid, minimize, mitigate, and/or recover from the effects of these climate-driven impacts—an effort collectively known as adaptation.

This guide is intended to provide tangible, replicable practices to help water[1] utility staff and water resource managers advance adaptation efforts in the face of climate change. Sea level rise adaptation is context-specific (e.g., by location, by asset, and by system), and while there is no one-size-fits-all approach to adaptation, there are principles—or leading practices—that may help water sector practitioners move towards on-the-ground implementation.

im·ple·men·ta·tion / impləmən'tāSH(ə)n/

: the process of making something active or effective; putting a decision, plan or project into effect; execution.

In this guide, implementation is defined as the process of making something active or effective that advances adaptation to sea level rise in a concrete way. This implies progress beyond understanding and assessing risk to executing policies (e.g., updated design standards), projects (e.g., building a desalination plant), process changes, or programs that proactively take action to boost resilience to climate impacts in the coastal zone (e.g., capacity building).

It is important to distinguish the difference between adaptation ***constraints*** or ***barriers*** and adaptation limits. Barriers include challenges or obstacles that slow or halt progress on adaptation but that can be overcome with a concerted effort. Alternatively, a limit is something that cannot, without unreasonable action or expense, be overcome (CoastAdapt 2017; Klein et al. 2014). An example of an adaptation limit would be the lack of physical space in a dense urban environment to create a nature-based solution, such as wetlands, as a coastal defense to sea level rise and storm surge. An example of an adaptation barrier is a lack of political will from organizational leaders.

There are many barriers that prevent adaptation implementation. The most frequently cited adaptation barriers include **governance, financial, technical, and social/cultural barriers.** These barriers, and suggested strategies to overcome them, are used to frame the content of this guide.

This guide is the outcome of a multi-year Water Utility Climate Alliance (WUCA) project designed to identify leading practices—recognizing that in this emerging dynamic field, "best practices" have yet to be established—to overcome these barriers. Tangible, real-world examples are provided when possible and help identify opportunities for the advancement of sea level rise adaptation measures.

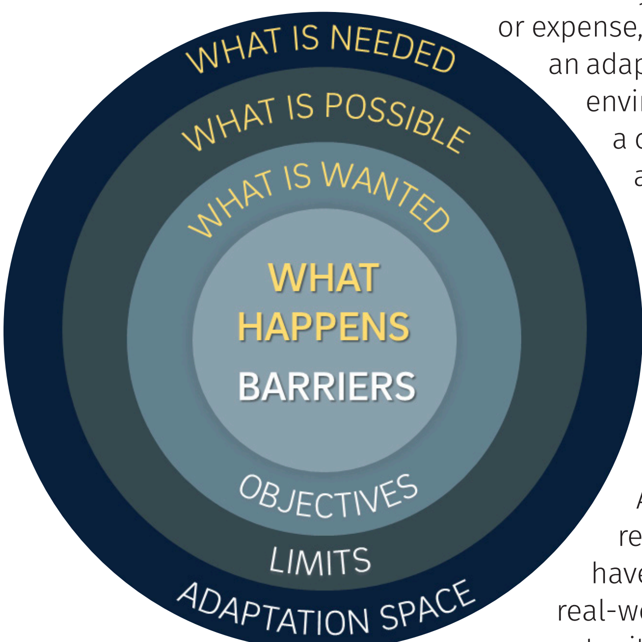


Figure adapted from Chambwera et al. 2014. (Graphic on page 952)
https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap17_FINAL.pdf

[1] Water utility or water sector used here generally encompasses the drinking water, wastewater, and stormwater sectors collectively.

IDENTIFYING LEADING PRACTICES

Expertise on adaptation options, common barriers to implementation, and opportunities for advancing action was solicited via a scientific and gray (e.g., white papers, agency reports, and plans) literature review, semi-structured interviews, a practitioner's forum with over 60 resilience leaders from around the U.S., and from the summation of the lived experience of the following WUCA Sea Level Rise Committee members: Philadelphia Water Department, New York City Department of Environmental Protection, Tampa Bay Water, San Diego County Water Authority, San Francisco Public Utilities Commission, and Seattle Public Utilities.

> *Leading Practices in Climate Adaptation,* published in 2021 by WUCA in collaboration with the Aspen Global Change Institute, identifies a series of overarching leading practices for climate change adaptation in the water sector. The report was developed through the first-hand experience of WUCA members, and the information is organized under five action areas: **Engage, Understand, Plan, Implement**, and **Sustain**. Adaptation action areas and the associated leading practices are presented in the form of a wheel, which illustrates their inherent interconnectedness. While there may be some linearity in the process (e.g., understanding, planning, and prioritizing of adaptation options leads to implementation), engagement with these adaptation action areas can happen at any stage.

This guide builds upon the success of that body of work and uses a similar format but focuses on one climate impact, **sea level rise.** Resources are provided for all adaptation action areas, but this document takes a close look at the **implement** phase and seeks to answer the question: What barriers are preventing the water sector from advancing past the vulnerability/risk assessment phase to actually implementing projects or policies that build resilience, and how can those barriers be overcome?

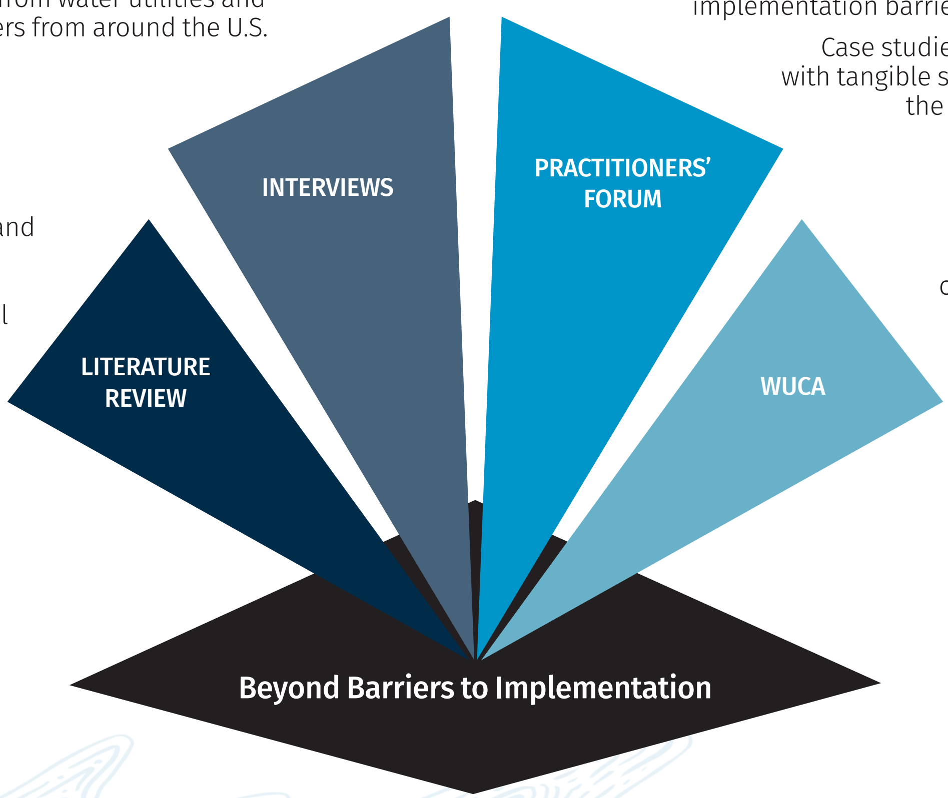
Over 16 semi-structured interviews were conducted with staff from water utilities and other resiliency leaders from around the U.S.

A convening of resiliency experts from coastal cities took place in June 2021 to discuss implementation barriers and opportunities.

Case studies and success stories with tangible solutions from around the U.S. were highlighted.

Literature (scientific and gray) was reviewed to identify barriers and solutions for sea level rise adaptation implementation.

WUCA Sea Level Rise Committee members contributed directly to this guide, providing leading practices and lessons learned from lived experience.



HOW TO USE THIS GUIDE

Water utilities and wholesale water providers do not function in a silo, and adaptation processes—from engagement to monitoring and evaluation of implemented strategies—must be coordinated with other municipal sectors and landowners, local organizations, tribal nations, community members, regional planning bodies, regulators, and all levels of government. Acknowledging this necessary coordination, this guide was developed with input from stakeholders in multiple sectors. Likewise, many of the leading practices and tools may be applicable beyond the water sector. However, leading practices particularly relevant to this field were chosen for inclusion, and it was developed from the water sector perspective with that audience in mind. It is meant to help other water utilities and resource managers begin implementing actions to adapt to sea level rise.

This Guide Does:

- Provide a high-level overview of the general steps required to initiate sea level rise adaptation and includes resources and tools to support each step
- Detail the most frequent challenges encountered when reaching the point of implementation
- Suggest solutions based on leading practices for overcoming barriers, using real-life examples when possible

This Guide Does Not:

- Provide a detailed roadmap with all the necessary steps to achieve sea level rise adaptation
- Provide a deep dive into the technical aspects of sea level rise, such as the science behind projections, working with tide level data, or risk assessment methods
- Examine every aspect of how sea level rise and related issues may potentially affect your water utility or your geographic location
- Provide a step-by-step adaptation plan and strategy for specific utility assets or system types

Guide Structure

This guide is organized as follows:

- **Sea Level Rise Impacts on the Water Sector –** this section provides useful context for the rest of the document.
- **Barriers to Adaptation in the Water Sector –** this section is organized by governance, technical, financial, and social/cultural adaptation barriers. Each barrier section provides a summary of the challenges, followed by leading practices to address them. Specific leading practices are identified and supported by targeted solutions using real-world examples. While each leading practice responds to one specific barrier, there are often case studies or practices that could apply as a solution to overcome multiple barriers.
- **Final Remarks –** this section summarizes the key findings that emerged while developing this report.
- **Appendices –** this section includes an extensive appendix section with resources and tools to assist with all adaptation action areas; an adaptation pathways and application matrix; and an extensive literature review covering sea level rise adaptation and risk management strategies for the water sector.

SEA LEVEL RISE IMPACTS ON THE WATER SECTOR

Since 1900, global sea levels have risen between roughly 6 to 10 inches (15 to 25 cm). Observed data indicate that the average rate of sea level rise increased over the twentieth century, and current projections show that the rate of these changes will continue to accelerate (Gulev et al. 2021). Currently, in the United States an estimated 133.2 million people live in coastal areas, putting them at risk of sea level rise-induced flooding, and populations continue to move closer to the coast every year (Fleming et al. 2018).

While sea level rise is a global phenomenon that is influenced by atmospheric warming and greenhouse gas emissions (e.g., melting ice and thermal expansion), the rate of rising and its consequences can vary significantly by location (Sweet et al. 2022). The local effects of sea level rise are heavily influenced by climatic factors such as weather events (e.g., storm surge), ocean circulation, and natural climatic variability (e.g., tidal fluctuations and El Niño Southern Oscillation[2]), as well as non-climatic factors, such as geological processes (e.g., vertical land movement, glacial isostatic adjustment[3], and tectonics), and human activities that alter the coastal zone (e.g., shoreline hardening, changes to sediment input, dune removal, and dredging), which can cause flooding that reaches farther inland. Higher sea levels amplify related impacts, such as storm surge, high tides, saltwater intrusion, wetland loss, and coastal erosion, which threaten coastal ecosystems, infrastructure, and communities(Azevedo de Almeida & Mostafavi 2016; Thorne et al. 2018; Oppenheimer et al. 2019).

Sea level rise, especially in combination with other climate hazards and weather events, presents compounding challenges that will affect drinking water, stormwater, and wastewater utilities' above and below-ground infrastructure and general operating capacity. Sea level rise may contaminate drinking water sources, and flooding may cause structural damage to treatment facilities, pumping stations, water intakes, underground pipes, and other assets within a utility's system. Impacts on gravity-fed drainage systems and facility damage could lead to the release of untreated wastewater and cause basement backups or infrastructure flooding in streets. These impacts from sea level rise could also put utility staff in danger and cause a facility to be completely or partially cut off from the surrounding areas, thus preventing staff from accessing critical locations that are crucial for operations. This can lead to disruptions in critical public services, a degradation of nearby natural habitats, and a loss of trust from the public.

Direct and indirect impacts of sea level rise and coastal flooding

- Increased erosion
- Increased damage to critical water infrastructure
- Degraded water quality (increased salinity of surface, groundwater, and aquifers)
- Degradation of coastal ecosystems and disruption of services they provide (e.g., water purification and filtration, flood protection)
- Increased displacement of residents, communities, and businesses
- Increased risk to public health and safety
- Increased disruption of or damage to critical services (e.g., transportation, hospitals)

[2] A periodic fluctuation in sea surface temperature and air pressure across the equatorial Pacific Ocean, occurring every 2 to 7 years. (Developed from National Oceanic and Atmospheric Administration)

[3] The ongoing movement of land in response to ice sheet loading and unloading. (Developed from National Oceanic and Atmospheric Administration)

ADAPTATION AND THE WATER SECTOR

Adaptation refers to efforts to avoid, minimize, and/or recover from the effects of climate change. Adaptation is an iterative process wherein decisions need to be implemented, monitored, and adjusted as needed based on practical experience as future conditions are realized; this is often referred to as **adaptive risk management**. Whether preparing for or responding to sea level rise or the combined effects of multiple climate change impacts, adaptation can be very context-specific (e.g., by site, by asset, by system). The best adaptation option for a utility in one coastal location may not be as effective for another utility in a different geography. In other words, there is no one-size fits all solution. Additionally, some sea level adaptation strategies may present a utility with multiple benefits that overcome multiple barriers.

When developing place-based sea level rise adaptation strategies, utilities should consider how solutions can be scaled or developed to address their unique adaptation needs while also providing additional benefits, or **co-benefits**, to their organization, ecosystems, and/or the community at large. For example, a levee to protect a treatment plant could be scaled to also protect nearby assets and neighborhoods, and its design could include civic and environmental amenities like paths, benches, native plantings, and new habitat areas. On an even larger scale, regional coordination is another important component of developing adaptation to sea level rise, as local flood-reduction strategies could increase inundation and its associated damages in other locations within the same bay or estuary (Hummel et al. 2021).

Water, wastewater, and stormwater infrastructure tends to be large and expensive, with long useful lifespans, so it is common for end-of-century projections to be considered for climate adaptation and resilience strategies. While sea level rise projections might be relatively certain through 2050 (globally they are increasing), the rate and magnitude of that rise is deeply uncertain, with projections diverging significantly after the 2050s. An adaptive risk management approach helps decision-makers address uncertainty and dynamic changes in both natural systems (e.g., how much will sea levels rise and how soon in a particular location) and sociopolitical systems (e.g., regulations, coastal population size, or coastal infrastructure) in order to implement adaptation options that are most effective and flexible over the long term.

The most successful adaptation strategies increase knowledge and collaboration between organizations and communities, which is a key component of advancing sea level rise adaptation. A number of coastal adaptation options are available to decision-makers, ranging from structural (e.g., seawalls and updated design standards) and nature-based (e.g., dunes and wetlands) approaches to policy and regulatory measures (e.g., zoning and floodplain regulations and retreat or relocation). The four common categories of strategies are **protect, accommodate, avoid,** and **retreat**. In practice, it is rare for these strategies to be employed in isolation, and usually, a combination of these strategies using physical solutions and policy-based tools is the most prudent way forward. When employing any of these strategies, it is important to develop equitable planning and investment strategies to ensure that sea level rise will not contribute further to the displacement of communities, low-income families, and Black, Indigenous, and People of Color (BIPOC)-owned businesses. Similarly, the carbon footprint of an adaptation strategy should be considered so it is not maladaptive, thus further exacerbating climate change.

Protection and **accommodation** strategies facilitate the continued use of the coastal zone by minimizing exposure to and damage from flooding (protection) or accepting higher water levels and occasional flooding by modifying coastal infrastructure and activities (accommodation). The loss of coastal sites to sea level rise is addressed by **managed retreat** strategies, wherein people and assets are intentionally abandoned or relocated to less vulnerable locations. **Avoidance** strategies aim to prevent or restrict development in areas vulnerable to sea level rise.

PROTECTING AND ACCOMMODATING WATER INFRASTRUCTURE AND SUPPLY

In the water sector, protecting and accommodating generally occur through two approaches, usually at different scales: (1) make existing or planned infrastructure (individual assets, systems or facilities) more resilient and/or (2) build a new asset dedicated to addressing the risk posed by sea level rise.

Increasing the resilience of existing or planned infrastructure at the asset level usually includes changing policies or updating design standards for new infrastructure and retrofitting existing infrastructure to protect from the impacts of sea level rise. It is often easier to employ these resiliency measures to new assets through a capital planning program while they are being planned and designed. Retrofitting tends to be expensive and challenging because of the scale, location (e.g., subsurface), and interconnected nature of water, wastewater, and stormwater infrastructure.

Building a new asset dedicated to addressing the impacts of sea level rise (e.g., flooding or water quality issues) could mean building a sea wall or dike, constructing a facility to address water quality concerns (e.g., a desalinization plant), or installing a new pumping system to ensure that sewer and stormwater systems drain properly. This approach is often costly, time intensive, and challenging to coordinate; however, in the long run it may be the more cost-effective and successful solution because it protects existing and future infrastructure and resources. Table 1 provides examples of protect and accommodate approaches and strategies for adaptation to sea level rise.

Table 1. Examples of Protect and Accommodate Sea Level Rise Adaptation Approaches and Strategies

APPROACH	STRATEGY
Protect	• Protect and restore natural habitats or construct nature-based solutions that can buffer sea level rise (e.g., wetlands, beaches, dunes). • Construct and maintain protective barriers (e.g., bulkheads, seawalls, tide gates). • Advance into the sea using land reclamation,[4] and build the new land to an elevation that protects new investments and those behind it.
Accommodate	• Develop new resilience design standards. • Retrofit infrastructure (e.g., elevate or floodproof structures, modify outfalls to prevent saltwater intrusion). • Implement floodable development measures (e.g., watertight pumps, submersible pumps, backflow prevention devices, floodplain reconnection projects). • Implement green stormwater infrastructure measures to help mitigate infrastructure flooding caused by the drainage system, which can be exacerbated by sea level rise (e.g., rain gardens and stormwater basins to capture precipitation before it enters the drainage system). • Create saltwater intrusion barriers. • Develop desalination and other water purification capabilities. • Recharge aquifers via injections of treated wastewater to slow land subsidence and flooding and prevent saltwater intrusion. • Diversify and increase water supplies and/or storage capacity (e.g., water trading, water reuse and recycling). • Increase water conservation efforts (e.g., educate water users regarding water shortages and quality issues associated with climate change).

[4] Land reclamation as an adaptation approach to sea level rise is often employed in island nations that have nowhere to “retreat” to or in dense urban coastal cities where the reclaimed land can not only help protect from rising seas but also alleviate crowded conditions. Reclaimed land provides development opportunities, which creates a financial incentive for taking on such a costly, large-scale project.

RETREAT AND AVOIDANCE IN THE WATER SECTOR

Municipal governments, which are largely responsible for planning in the coastal zone, must balance the demand for development with protecting citizens, preserving cultural resources, and conserving open space and the environment. As sea levels rise and exponentially increase risks along the coast, local governments are increasingly using legal tools to advance avoidance and retreat strategies to adapt to changing conditions. Both retreat and avoidance actions are highly specific to the local geography and community dynamics and require significant coordination between organizations, including political offices, other government agencies, local communities, and utility/services providers. These strategies are often complex, politically charged, and cannot be implemented by the water sector alone. The decision to use these two adaptation approaches falls largely outside of the purview of a water utility; if the community lies in vulnerable coastal areas or new development is approved in those locations, the infrastructure to provide water, wastewater, and stormwater services generally cannot be unilaterally removed, moved, or withheld. This highlights the importance of coordinated holistic adaptation strategy development with input from multiple stakeholders and sectors across the municipality and region.

Several other things make it challenging for the water sector to consider avoidance and retreat adaptation strategies. For example, both approaches require putting physical distance between assets/operations and the source of flooding. Distancing from the coast or river may be impossible—or prohibitively expensive and logistically difficult—for water utilities if they rely on surface water bodies for their operations (e.g., sourcing water from rivers or gravity-fed drainage systems that manage wastewater and stormwater with outfalls along the coast).

While a utility may be able to strategically phase out their most vulnerable assets and place new assets in less vulnerable locations, the interconnected nature of water infrastructure often dictates or limits infrastructure placement, which makes accommodation and protection strategies more viable adaptation options, at least in the near term. For example, a pumping station to help move water through a wastewater treatment plant will need to be nearby the plant itself, which may already be in a floodplain where it discharges into a coastal water body. Water utility scope and directive vary widely, but this common reliance on coastal areas makes avoidance and retreat strategies more challenging to adopt when adapting to sea level rise.

Retreating from the coastline or avoiding development in vulnerable coastal areas requires careful consideration of the communities impacted, equity challenges and justice effects, changes to zoning and floodplain regulation, strategic political guidance, and a calculated look at infrastructure networks. Every water utility's relationship with relevant external entities and their internal capacity to address the complex impacts of retreat make this a more difficult set of strategies for water utilities to employ on their own. For this reason, many of the leading practices provided in this guide focus on strategies that protect and accommodate. Yet, there are important examples provided here of communities that are taking steps to retreat and prevent development in vulnerable locations in the first place. Over time, as sea levels rise and the risks increase, these strategies may emerge as the only viable long-term solutions. Table 2 provides examples of avoidance and retreat strategies; note that these strategies are not specific to the water sector and in most cases will be enacted or led by other municipal departments (e.g., the department of planning and development).

Table 2. Examples of Avoidance and Retreat Sea Level Rise Adaptation Approaches and Strategies

APPROACH	STRATEGY
Avoid	• Use policy and regulatory tools to limit development in vulnerable areas. • Establish conservation land trusts to preserve and restore natural environments that can provide a flooding buffer. • Implement solutions that conserve and protect coastal ecosystems (e.g., living shorelines). • Work with other agencies to establish zoning and overlay zones that specifically ameliorate coastal risk. • Work with other agencies to establish setbacks and buffers to limit development in high-risk flood zones and require that natural protective systems (e.g., dunes) remain intact.
Retreat	• Managed retreat of people and communities out of high-risk areas by relocating and realigning structures inland to less flood-prone areas. • Phase out maintenance of at-risk infrastructure (infrastructure disinvestment) and instead invest in infrastructure in less vulnerable locations. • Set up buy out and land acquisition programs for frequently flooded coastal land. • Establish rebuilding restrictions to limit a property owner's ability to rebuild structures destroyed by natural hazards, such as flooding. • Use incentives, such as cluster development or transferring development rights, to promote development in less vulnerable locations, and discourage development in areas vulnerable to sea level rise and storm surge.

It is important to note that, in practice, water utilities do not rely on only one set of adaptation strategies but instead build resilience pursuing various pathways simultaneously. The sea level rise adaptation strategies and approaches outlined above are easy to list on paper, but implementing these actions is often hindered by significant challenges and barriers. The next section dives into the specific barriers and leading practices to overcome them.

Equity and Environmental Justice

Fully addressing equity and environmental justice impacts and challenges are outside the scope of this guide, but several of the leading practices outlined here provide opportunities to begin addressing these social ills while simultaneously building climate resilience. In fact, the two are inextricably linked; we will not successfully adapt if our most vulnerable populations—including people of color and low-income communities—are not protected and given the tools to thrive.

It is important that water sector practitioners understand the disproportionate impacts marginalized communities face. Marginalized communities – including low-income communities, communities of color, indigenous peoples and tribal nations, and immigrant communities – tend to be disproportionately impacted by climate change more than other populations. While complex and location-specific, this disproportionate impact generally stems from unjust systems that have been in place for many decades (e.g., underinvestment, exposure to pollution and toxins, poverty, limited access to public services, predatory inclusion, discriminatory lending practices, redlining, and outdated infrastructure systems). These entrenched systems are extremely difficult to overturn and require dedicated proactive work.

It is vital that water utilities recognize the structures in place that may result in unequal impacts and actively work to break down these injustices. The water sector and government entities must develop equitable planning and investment strategies to ensure that sea level rise will not contribute further to the displacement of marginalized communities, low-income families, and BIPOC-owned business. Establishing level of service goals/standards and considering how climate change will impact them, is one approach water utilities can use to ensure that services are equally distributed. To reach the standard, investments may need to be concentrated in areas that have historically been excluded from infrastructure upgrades or have deferred maintenance, ensuring that everyone has equal access to the same basic services.

As utilities search for adaptation solutions that build resilience, an equity lens is an essential part of building community resilience and adapting to sea level rise. Water sector practitioners must come to the table ready to partner with and listen to community advocates throughout the entire adaption process. These conversations and partnerships are a necessary first step to begin correcting the egregious wrongdoings of the past.

Equity is a priority in WUCA's Five-Year Strategic Plan. WUCA has committed to "incorporate consideration of equity into all WUCA's work", and is currently engaged in a multi-year partnership with the US Water Alliance to advance water equity and climate resilience so that equity is a priority in the climate adaptation efforts of WUCA and individual member utilities.

BARRIERS TO ADAPTATION IN THE WATER SECTOR

Sea level rise adaptation may be hindered by any number of factors. Barriers consistently expressed by water sector planners and managers include lack of political urgency, lack of adequate and quantifiable information about potential sea level rise impacts, the long planning timeframe required to address sea level rise juxtaposed with short-term political cycles, lack of direction from state agencies, inflexible permitting and zoning processes, and a lack of funding and other resources to take action.

The barriers to adaptation implementation can be categorized as follows:

Governance barriers, such as the presence and flexibility (or lack thereof) of regulatory and policy measures, challenges due to political jurisdictions and boundaries, changing priorities due to election cycles;

Financial barriers, such as design/construction and maintenance costs of adaptation measures, as well as the availability and flexibility of funding sources;

Technical barriers, such as limits in the availability of feasible adaptation options (including the capacity to implement the best available options), and the ability of adaptation options to effectively reduce the impacts of sea level rise; and

Social or cultural barriers, which may arise from conflicting interests of stakeholders and/or sectors (e.g., public versus private landowners, disproportionate impacts on marginalized groups).

The goal of this guide is to provide guidance on how to overcome these barriers and identify opportunities for the advancement of sea level rise adaptation measures.

The barriers and leading practices presented herein are products of interviews with coastal water utilities, WUCA member questionnaires, case studies found in the literature, and information exchanged through a forum with resilience leaders from around the U.S.

Where applicable, leading practices are followed by a bulleted list of real-world examples of that practice from the utilities that were studied. Some of these examples include links to tools and documents that support specific projects, adaptation actions, or barriers. The examples in this section include icons depicting when they represent stormwater, drinking water, or wastewater utilities.

stormwater **drinking water** **wastewater**

gov·ern·ance / ˈgəvərnəns /

: the action or manner of governing or overseeing the control and direction of something; the *way* in which something is governed

GOVERNANCE

In the context of this guide, governance barriers are those related to the organizational aspects and administration of work to address sea level rise. Governance barriers include a lack of leadership; unclear definition of roles and responsibilities; a siloed work environment; an unaccommodating institutional framework; a lack of awareness or understanding of the issue; competing timeframes and scenarios used to make decisions; legal uncertainty; competing priorities; opposing approaches to address the problem; and rigid regulatory and policy measures or a lack of necessary policy measures. The cross-cutting and “super wicked” nature of climate change exacerbates the governance barriers and challenges already seen within the water sector (Levin et al. 2012).

The organizational structure of a utility (e.g., units and divisions) is shaped by the services provided, and staffing needs are often based on meeting “level of service” goals and fulfilling regulatory obligations. There is often no regulatory driver for climate adaptation, so addressing sea level rise may not be assigned to a particular unit or staff person—nobody “owns” the issue. Staff may be concerned about sea level rise but feel overwhelmed by the issue on top of their established tasks, or they simply may not have the tools or expertise to address it.

Sea level rise adaptation solutions need to be scaled appropriately and are best addressed in a regional, holistic manner. This introduces another challenge: broad collaboration and communication with the right stakeholders. This may mean working with different units and administrative levels within your organization as well as coordinating/partnering with outside stakeholders, including other city departments and agencies, regional planning groups, community members, the private sector, and local, state and federal government. For example, if a water utility is interested in protecting a facility from coastal flooding, the ideal adaptation solution would provide multiple benefits across various sectors; leverage resources; and simultaneously protect other critical facilities, city-owned infrastructure, businesses, and neighborhoods in the vicinity. Aligning priorities and timelines, performing assessments, conducting outreach, developing designs, obtaining permits, and securing funds for a coastal adaptation project at this scale is extremely challenging and requires extensive coordination.

LEADING PRACTICES

Internal staff capacity needs to be a core investment strategy for sea level rise adaptation. Develop guidance, tools, and policies to empower your colleagues and ensure that climate change information is used in the work they do.

The internal capacity of agency staff to advance sea level rise adaptation needs to be strengthened and supported by leadership. This may entail hiring new staff to focus on climate adaptation, investing in new tools or training for existing staff, or acquiring contracts with consultants to support internal efforts. Climate adaptation planners can make it easier for their colleagues by directly engaging with operators, engineers, and managers and providing climate adaptation tools and information relevant to their tasks and deliverables. Staff can further be exposed to climate topics through external speaker presentations, working groups, and increased discussions with climate experts internal and external to the utility. While investments to build internal capacity will require dedicated funds, they are the first–and arguably the most important–step an institution can take to build resiliency.

The **Philadelphia Water Department (PWD)** recently adopted a policy requiring the use of **Climate-Resilient Planning and Design Guidance**. The guidance, which was developed by PWD's Climate Change Adaptation Program, equips staff with the tools and climate information necessary to mainstream the best available climate science into existing plans, projects, programs, and standards. Implementation of the guidance will ensure staff builds resiliency into the work they do to maintain, upgrade, and replace PWD drinking water, wastewater, and stormwater infrastructure. To fully empower staff to use the guidance, it was necessary to develop and adopt a department-wide policy. Building the case for guidance implementation and adoption of a policy involved years of internal outreach and education, including climate 101 presentations, listening sessions, sending resources from trusted voices (e.g., American Society of Civil Engineers guidance), and working with identified climate champions to internally build support, while stressing the importance of thoughtful communication and outreach strategies.

The Portland Water Bureau (PWB) in Oregon recently created a 5-year Strategic Plan that identifies climate change as a key priority and builds on a legacy of over 20 years of planning for climate change by the utility. However, "mainstreaming" or integrating climate change adaptation and planning throughout the water utility has been challenging over the years given the size of the organization, the different functions of work groups, and competing priorities. To address this challenge, the agency has invested resources over ten years to build internal staff capacity for climate change modeling and adaptation, including developing a specific Climate Resiliency Planning Manager position and hiring a Water Resource Modeler. These staff work with engineers and operators in the utility to provide resources and tools to help incorporate climate change information (including sea level rise, flooding, extreme heat, and drought) into engineering planning, asset management, facility/system operations, and water resource planning. The organization also established a set of Director's Climate Commitments to further embed climate change into the daily work of the utility and specific projects, including a commitment to "integrate meaningful climate analysis into engineering project planning."[5]

[5] Heyn K. 2022 September 25. Personal communication [Personal interview and WUCA member questionnaire].

Consider broad social and regional consequences that result from government decisions, policies, and programs and attempt to anticipate unintended and unexpected consequences.

Certain actions may incite public backlash and disengagement, exacerbate existing inequities, cause displacement of residents, or transplant a problem to a different location (e.g., building a seawall in one location could make flooding worse in another area). To avoid unintended consequences, engage professionals and stakeholders from diverse organizations and agencies to understand their values and concerns and strive toward clear communication on priorities, benefits, and goals.

Image courtesy of Miami-Dade County

Sea level rise can reduce the effectiveness of a drainage system as higher water levels cover outfalls and make it harder for water to flow from the system under the force of gravity. Sea level rise in combination with extreme precipitation events (e.g., heavy rainfall due to hurricanes) and especially high tides (e.g., king tides, storm surge during hurricanes) further exacerbates this issue, causing flooding inland as excess stormwater has nowhere to go. Flooding can also result from the stormwater infrastructure itself and act as a conduit for seawater backflow through street drains. With sea level rise, groundwater levels also increase and can breach the ground surface in low-lying areas, thus further exacerbating these infrastructure-related flooding issues. As neighborhoods get inundated and runoff flows over land, it picks up and transfers pollutants (e.g., fertilizer, pesticides, nutrient inputs, vehicle oil, as well as human and animal waste). These pollutants can impact the well-being of residents and ecosystems in coastal cities—especially marine and freshwater ecosystems if the pollutants make their way into receiving waterbodies (e.g., bays, estuaries, and coastal zone). The influx of pollutants into local waterways can reduce water-based recreation due to residents' health and safety concerns, impacting the local tourism economies and quality of life. The ecological impact of these pollutants can include large fish kills, algal blooms, loss of seagrasses, and their potential ingestion by endangered or threatened species.

Image courtesy of Miami-Dade County

Miami-Dade County, Florida experiences these flooding issues as "sunny day flooding" on a regular basis when there are large tides (e.g., king tides), even in the absence of storm events. To address chronic flooding in neighborhoods, in 2017–2018 the City of Miami Beach elevated streets and installed 70 one-way stormwater pumps in low-lying, flood-prone areas. These efforts were successful at reducing flooding from neighborhoods, but the pumping had the unintended consequence of adding pollutants and degrading the ecosystem in Biscayne Bay. To address this ongoing issue, the Miami-Dade County Division of Environmental Resources Management (DERM) and the City of Miami Beach enacted several measures to mitigate the negative impacts of runoff on the Bay, including adopting new fertilizer ordinances, establishing a local task force, investing in stormwater innovation projects, and public outreach initiatives (Jaramillo 2022; Miami-Dade County 2022a; Miami-Dade County 2022b). Additionally, as of 2020, the City of Miami Beach modified pump outfall designs to include dissipator boxes, initiated a $133 million sanitary sewer upgrade program, and created an environmental inspection program with the goal of reducing sewer overflows and construction run-off (City of Miami Beach 2021).

It is easy to get stuck in analysis paralysis – be prepared to spend as much time, or more, on developing an implementation and funding plan as you did on identifying vulnerabilities and assessing risk.

Do not spend all of your sea level rise adaptation planning time and resources on modeling, vulnerability assessments, and outlining potential strategies. Invest an equal amount of time, or more, in developing an implementation plan that includes design and construction timelines, permits and regulatory requirements, and funding mechanisms (e.g., capital planning budgets and grant opportunities).

Have assessments and action-oriented recommendations ready before the next extreme event and make sure that risks and adaptation projects are included in local hazard mitigation plans.

Unfortunately, it often takes an extreme event for local political leaders and decision-makers to understand the risk that extreme events and climate change pose. Therefore, having plans ready for implementation that could be quickly adopted following a disaster is a smart approach. Ensuring that climate risks are acknowledged and projects to address them are included in local hazard mitigation plans is an important step for accessing federal funds. For example, after an event has a Presidential disaster declaration, the Federal Emergency Management Agency's (FEMA) Hazard Mitigation Grant program can be used to implement projects that reduce the impact of climate change, such as drought, coastal erosion, and flooding, but only if those risks and mitigation projects have been specifically identified in the local hazard mitigation plan.

Look for innovative ways to coordinate across departments and work with communities, such as a Joint Benefits Authority, to leverage resources, align funds, and aid project coordination.

A Joint Benefits Authority (JBA) is being tested as a mechanism to bring multiple city departments together in partnership with communities to develop infrastructure projects that address climate change and build community resilience. Traditionally, it is challenging to work across departmental silos and with the community on large-scale projects that require coordinated objectives, timelines, and funding. Ownership and maintenance issues are also constraints for collaborative projects that provide multiple benefits. The creation of a **JBA** that can issue bonds and align them across agencies can then address barriers that separate agencies and departments and help them work more easily with the community. The JBA establishes a mechanism for joint funding, accountability, strategy development, monitoring, implementation, and community partnership. The JBA tool is being piloted in San Francisco and was developed by the World Resources Institute with partners, including the **San Francisco Public Utilities Commission.**

Leverage regulatory tools to limit or avoid further development on land that is vulnerable to sea level rise and encourage nature-based solutions with multiple benefits.

Coastal and land use regulations that limit or prohibit development in the coastal zone can reduce flood risk to communities that are vulnerable to sea level rise. Some examples of regulatory tools include land-use zoning overlays[6] that impose additional resilience requirements on development in coastal areas or limit development altogether; set back or buffer requirements that prohibit development a certain distance from a baseline (e.g., high tide mark); floodplain regulations that add a safety factor to account for sea level rise; or regulatory incentives that provide co-benefits, such as living shoreline solutions to protect private properties over engineered built solutions such as a bulkhead. Regulatory tools can come along with pushback from the development community and complex legal considerations specific to the given area, so it is important to understand the political and legal frameworks in place when exploring the adaptation strategies available.

[6] Areas or districts that can impose additional regulations based on special characteristics in that zone, such as for natural, historical, or cultural resources protection (Developed from Georgetown Managed Retreat Toolkit).

Norfolk, Virginia, recently enacted **zoning regulations** to require all new development and redevelopment to meet "resilience quotient" criteria (unless exempted, e.g., historically or architecturally significant buildings or buildings with gold-level or higher LEED certification). The zoning ordinance was created to enhance development practices so they promote flood resilience in the city by taking into consideration factors such as conservation of water resources, management of stormwater, flood risk reduction, energy efficiency, and protection of water quality. New development must earn a certain number of points to be in compliance with the resilience quotient standards[7]. All new buildings within the 100-year floodplain are now required to comply with a 3-foot above the 100-year base flood elevation freeboard[8] standard; the former standard was 1-foot above the 100-year base flood elevation. New developments can also gain resiliency points for stormwater management compliance which includes reducing impervious areas as well as installing green infrastructure and other stormwater infiltration systems (City of Norfolk 2021).

In 2011 **King County, Washington,** initiated an update to its floodplain mapping and development standards to protect structures and communities along its shorelines from the impacts of sea level rise. The County included sea level rise projections in an assessment of its existing FEMA 100-year floodplain boundary and proceeded to incorporate sea level rise into its coastal floodplain building regulations (FEMA-designated flood zones). This code change became known as the **Sea Level Rise Risk Area** and extends the edge of the regulated floodplain boundary inland until the land intersects with +3-feet above the 100-year base flood elevation (BFE) for that location. The areas within this extended floodplain have the same code requirements as the mapped FEMA 100-year floodplain. The width of the Sea Level Rise Risk Area is not uniform and varies due to topography. Structures built in the Sea Level Rise Risk Area (those that go beyond the boundary of the FEMA 100-year floodplain) do not have to carry FEMA flood insurance because they are not located in the FEMA designated zone. However, they are required to be +3 feet above the BFE and pass engineering specifications required by the County. Additionally, no new groundwater wells are allowed to be installed in the existing 100-year floodplain, and if a building is located on a bluff, the setback requirements were changed from 50 feet to 75 feet unless a geotechnical study is completed to prove that a structure is not prone to sliding. The code change and related policies are only applicable to Vashon-Maury Island, which is an unincorporated area where King County acts as the local government.

The County code change and resulting FEMA floodplain maps officially became effective in 2020 with the adoption of the County's 2020 comprehensive plan update. This update included a series of public meetings and engagement efforts, and the County walked through sea level rise concerns and proposed regulations with the Vashon-Maury Island community. The County is working on implementing and communicating the new code changes to developers and property owners and has created parcel reports to view the boundary limits and better visualize the new requirements. The updated code was adopted unanimously with no public objection. The County attributes this in part to the fact that the new regulation only covers new development and major remodels. The Vashon-Maury Island shoreline is already very developed with limited new space, so many property owners were not greatly impacted by the change. King County's new code regulation has the highest BFE requirements in the state.[9]

[7] Shea P. 2020. August 19. Personal communication [Personal interview].

[8] An additional amount of height above the Base Flood Elevation used as a factor of safety in determining the level at which a structure's lowest floor must be elevated or floodproofed (Developed from Federal Emergency Management Agency).

[9] Whitely-Binder L. 2021. September 21. Personal communication [Personal interview].

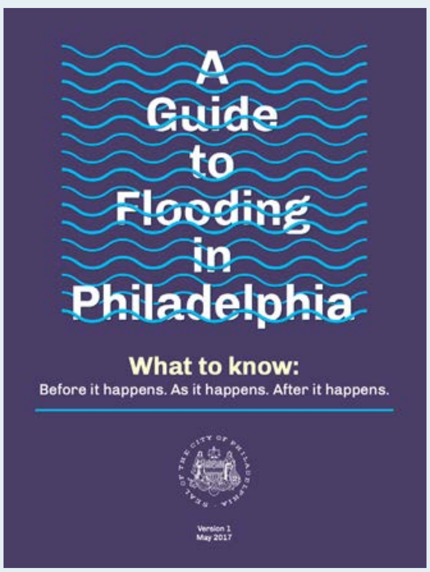
Collaboration across jurisdictions, different levels of government, departments, and stakeholder groups will be required to address the complexity of large coastal protection projects/efforts and bring independent priorities into alignment.

In most places, there is no centralized agency responsible for addressing sea level rise or other climate change risks, which makes collaboration and partnerships essential for aligning priorities, leveraging resources, and holistically advancing resilience. The larger the project, the more important stakeholder engagement is to ensure coastal adaptation solutions are considered across sectors and agencies with co-benefits for the community. For example, strategies to prevent or limit storm surge impacts may require careful consideration of the drainage network to ensure it can function properly during flooding events. Creating an avenue for communication between agencies and community organizations/members ensures that solutions will work for all parties and can lead to multi-benefit solutions, build synergies between projects, and establish an orchestrated output of adaptation action in sea level rise risk areas. These large-scale coastal protection projects can be complex, extremely costly, and require regional coordination.

San Francisco's Ocean Beach Project is an example of multiple city, state, and federal agencies collaborating to develop and implement adaptation strategies to address sea level rise, coastal erosion, and flooding. Several implementation projects are underway, including the Ocean Beach Climate Change Adaptation Project led by the City and County of San Francisco and the San Francisco Public Utilities Commission with support from the San Francisco Municipal Transportation Agency, the San Francisco Recreation and Park Department, and the Army Corps of Engineers. The project will implement concepts developed in the **2012 Ocean Beach Master Plan** which outlines the challenges sea level rise will bring to San Francisco's Ocean Beach and recommendations for how to address these challenges. The **Ocean Beach Climate Change Adaptation Project** focuses on the implementation of managed retreat through closing/rerouting the Great Highway between Sloat and Skyline Boulevard; protecting the Lake Merced Tunnel, Westside Pump Station, and the Oceanside Treatment Plant; introducing a multipurpose protection and restoration system; and removing existing shoreline armoring from the beach. The Ocean Beach Coordination team reviews projects in the region and engages with local communities and stakeholders to understand and respond to the complexities that arise with such a large-scale project dealing with transportation and wastewater infrastructure, networks of parks, natural landscapes and recreation areas, as well as the impacts these changes will have on local residents.

The Boston Water and Sewer Commission (BWSC) is an independent entity that provides water and sewer services to the City of Boston, Massachusetts. Like many utilities, BWSC does not own the properties where existing utility structures are located, nor do they own property where new structures may be needed, which makes adaptation implementation challenging. For example, BWSC may identify a piece of land that would be the best location for a new dam or for a project to update their wastewater system, pumping facility, or holding tanks, but the land may be privately owned or owned by the City, and BWSC does not have the jurisdiction to initiate a project there. BWSC has identified that strong partnerships with other city agencies has been a key to overcoming these challenges surrounding land use and land ownership.

BWSC is working with the City's Parks Department to conduct preliminary studies on Parks' property to identify options for stormwater holding basins where water could be temporarily held during flooding events as well as where new facilities could be built in the future as needed. The intention is that BWSC would treat the stormwater running through Parks' properties, and if there is a flooding event, they could shut down the treatment facility and hold the water until flooding subsides. BWSC is also working with the Parks Department to identify locations to build and/or restore wetlands. They have identified 10 candidates for water storage in parks and open spaces. At this stage, these strategies are only plans, but BWSC continues to work closely with the City and local partners, including the environmental business council, business owners, and consulting groups, to collaborate on developing adaptation strategies that will benefit multiple parties.[10]



Credit: City of Philadelphia

The **Philadelphia Citywide Flood Risk Management Task Force** is an interdepartmental collaboration that was formed in 2015 as a way to holistically tackle flooding issues across the city of Philadelphia, Pennsylvania. A memorandum of understanding was used to bring eight city departments (Philadelphia Water Department, Philadelphia City Planning Commission, Office of Emergency Management, Office of Sustainability, Philadelphia Streets Department, Philadelphia Parks and Recreation, Licenses and Inspection, and Health Department) and other partners together to address riverine, coastal, and infrastructure-based flooding. The task force was created to leverage the City's resources and outreach for addressing flooding issues. Goals include increasing inter-agency coordination on citywide and neighborhood-level flood risk management strategies and fostering sustainable, sensible city planning and development.

In 2017, the Task Force released **A Guide to Flooding in Philadelphia**, an outreach tool directed toward property owners and residents. To further support Task Force goals, in 2018, the City hired its first floodplain manager. More recently, outreach efforts have targeted specific communities prone to flooding, and direct collaboration with impacted communities led to the creation of a **neighborhood-led flood risk management task force**.

[10] Sullivan J & Jewell C. 2020. August 25 and 27. Personal communication [Personal interview].

Consider private-public partnerships as a way to share costs and risk.

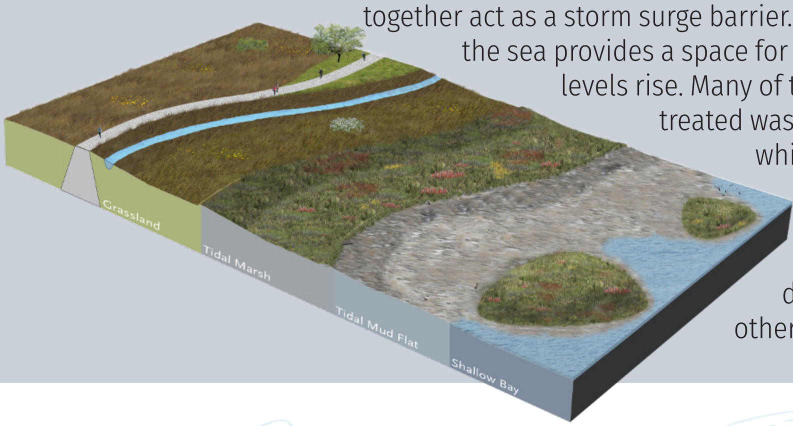
While it may not be the right solution for every project, there are times when public-private partnerships provide a unique opportunity to bring high quality and sustainable infrastructure projects to fruition. Such partnerships rely on strong relationships between private and public sectors, drawing on the strengths of each party who share in the cost, maintenance, and overall responsibility, and allow for more ambitious projects to get off the ground due to reliable investments from each entity.

The **San Diego County Water Authority (SDCWA)** purchases water from the **Carlsbad Desalination Plant**, which provides the San Diego, California, region with 10 percent of its drinking water needs (about 50 million gallons per day, enough for 400,000 people). The desalination plant, along with a 10-mile conveyance pipeline, was built by Poseidon Water, a water infrastructure development company. The Carlsbad Desalination Plant provides drought-proof and locally controlled water, thus creating a reliable system and water security. A public-private partnership between Poseidon Water and SDCWA has been essential in the success of the desalination plant. The Water Purchase Agreement used between Poseidon Water and SDCWA "assigns appropriate risks to the private sector while keeping costs for water rate payers as low as possible. The agreement transfers to Poseidon and its investors the risks associated with design, construction and operation of the desalination plant." These types of partnership can be an important part of a water management strategy as water resources become more limited and the production of new, local supplies are required to support water supply resiliency efforts (SDCWA 2020).

For large-scale coastal protection projects, anticipate implementation challenges such as permitting and long-term maintenance agreements, and work with stakeholders and regulating agencies as early in the process as possible to work towards solutions.

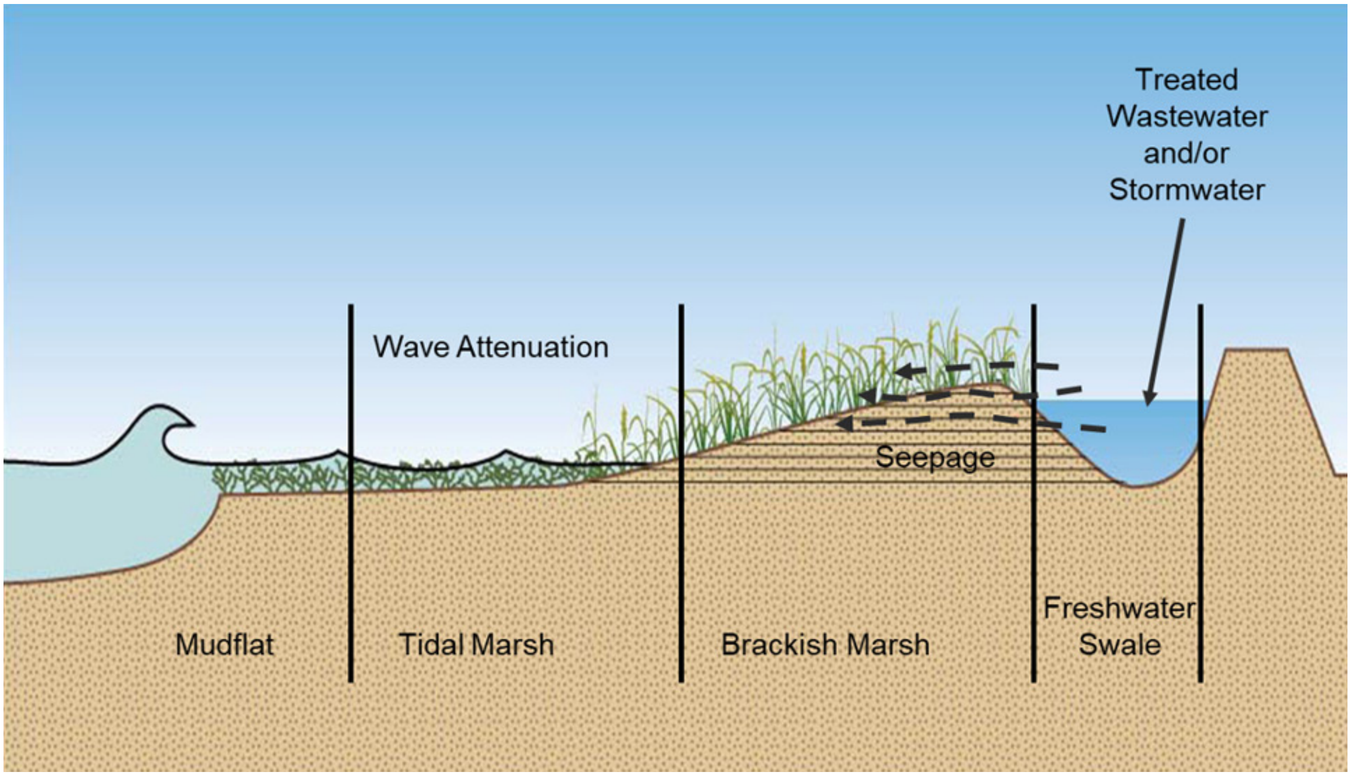
Large-scale coastal protection projects often run into implementation challenges related to permitting, maintenance agreements, and cost-share agreements. Anticipating these challenges and working directly with key stakeholders, such as local and state regulating agencies and the United States Army Corps of Engineers (USACE), to address challenges early on is essential to avoid project delays or cancellations.

In California, there are currently half a dozen projects attempting to install horizontal levees, a nature-based solution with multiple benefits that include climate resilience, social benefits, and ecological and habitat improvements. The Horizontal levee design combines a levee with a sloped wetland on the waterside, which together act as a storm surge barrier. The sloped land between the levee and the sea provides a space for wetlands to migrate upward as sea levels rise. Many of these projects are designed to use treated wastewater effluent to irrigate the wetland, which provides nutrient removal to improve water quality. Horizontal levees also create additional wildlife habitats and benefit the community when their designs incorporate nature paths and other amenities.



Credit: ESA PWA. 2013. Analysis of the Costs and Benefits of Using Tidal Marsh Restoration as a Sea Level Rise Adaptation Strategy in San Francisco Bay. https://bayecotarium.org/wp-content/uploads/cost-and-benefits-of-marshes-.pdf

In the **City of Hayward, California**, the East Bay Dischargers Authority (EBDA), a Joint Powers Public Agency of wastewater agencies in the San Francisco Bay Area, is leading an effort to design and acquire permits for the construction of an innovative, full-scale horizontal levee to build resilience to sea level rise and improve water quality. EBDA is working with several partners, including the Hayward Area Shoreline Planning Agency, on the ambitious First Mile Horizontal Levee Project. In October 2021, a pre-permitting consultation for the project was held to identify and discuss permitting issues, which highlighted a number of areas where regulatory agency feedback is contradictory and/or creates obligations that could make the project infeasible or prohibitively expensive. EBDA is working with local partners and stakeholders to try and address these permitting challenges and seek solutions with policy-makers. For example, the San Francisco Estuary Partnership, another partner on the project, is developing a white paper and workshop process focused on regulatory barriers to the implementation of horizontal levee projects around San Francisco Bay.[11]



Credit: PWA.2010. Preliminary Study of the Effect of Sea Level Rise on the Resources of the Hayward Shoreline (PWA Report 1955). Hayward Area Shoreline Planning Agency. https://www.hayward-ca.gov/sites/default/files/HASPA%20Preliminary%20Study...%20PWA%202010.pdf

[11] Warner J., Zipkin J. 2020, October 23 and 2022, February 21. Personal communication [Personal interview].

fi·nan·cial / fəˈnan(t)SH(ə)l, fīˈnan(t)SH(ə)l /

pertaining to monetary receipts and expenditures; pertaining or relating to money matters

FINANCIAL

Financial barriers include upfront costs and those associated with the maintenance of adaptation measures, as well as the availability and flexibility—or lack thereof—of funding sources. Drinking water, wastewater, and stormwater infrastructure are in urgent need of repair because many systems have outlived their intended lifespan. Therefore, it is hard for an adaptation project, which is likely not required for regulatory compliance and that has high up-front costs but the potential for long-term savings, to compete with a capital project addressing a near-term need. Priority must be given to projects and upgrades that keep a system functioning and in compliance; however, without the appropriate climate information and established resiliency standards, the opportunity is lost to make these assets resilient to sea level rise and other climate impacts. Improved and standardized cost-benefit-analysis formulas that include the cost of inaction (e.g., damages from an extreme storm) are needed to make the business case for adaptation investments.

Given the interconnected nature of drinking water, wastewater, and stormwater infrastructure and the fact that many assets are underground, changes to these systems can be extremely expensive. For example, it is generally seen as cost-prohibitive to dig up and raise a gravity-fed stormwater or wastewater system that is vulnerable to rising seas, which therefore limits the solutions available. Additionally, bond rating agencies, an important player in municipal utilities' ability to borrow funds, are now considering downgrading bond ratings if the municipality is not actively preparing for climate change. While this development hopefully incentivizes climate adaptation planning, a city or utility behind in this work could have a limited ability to borrow the funds necessary for adaptation projects or building staff capacity.

An inherent flaw in the funding structure of most utilities further exacerbates the financial barriers outlined above. Unless the utility is a private for-profit company, generally all operational and capital funds are generated by a fee or rate based on usage; there is no profit. However, usage has been decreasing for several reasons. With climate change adding to water scarcity issues in many parts of the world, there has been a massive effort to conserve water. In addition to successful conservation campaigns, appliances like low-flow toilets and high-efficiency washing machines have meant that people use less water. Yet the price to treat and distribute drinking water or treat wastewater remains fixed—or in many cases has increased due to climate change and other external factors. Raising rates can be a hardship for socially vulnerable communities who are also disproportionately impacted by climate change, thereby bringing equity issues to the forefront of these challenges.

LEADING PRACTICES

Develop a funding strategy that includes a menu of funding options.

Funds for large projects are unlikely to come from one place. There needs to be multiple streams of revenue or options for funding (e.g., federal programs, state bond programs, parcel taxes, and grants). Being cognizant of the time frame of receiving grants and when and how the funds are available once received is essential. The turn-around time and resources necessary to submit grant applications are important factors to integrate into a funding strategy and can be helpful when creating an implementation plan and expected timeline for a project.

San Francisco's Planning Department developed a **funding strategy** for its Islais Creek project, which addresses the impacts of sea level rise along San Francisco's Islais Creek shoreline. Funding and financing strategies are organized into near-term and long-term categories; are accompanied by implementation details; and can be re-organized by project type, geography, and project cost.[12] The Islais Creek funding strategy document also contains a number of key considerations and challenges for the implementation of adaptation strategies. With regards to funding considerations for future projects, the document recognizes that the financing landscape is variable, depending on politics and the economy, and is constantly changing. Some recommendations mentioned to address this challenge include (1) it would be "more efficient to wait to pursue specific funding and financing strategies for longer-term projects"; (2) "consider implementation mechanisms and revenue sources that provide flexibility to adapt over time to meet changing needs"; (3) leveraging an adaptation pathways framework; and (4) "prioritize opportunities to create long-term revenue streams" (AECOM 2021, pg. 13).

To address its coastal flood risk, which will increase with sea level rise, the **City of Punta Gorda, Florida,** relocated its public works facility inland to a less flood-prone area, installed living shorelines, is building a new emergency center at a higher elevation with storm-resistant features, and upgraded its stormwater management system by installing tidal flex valves to reduce tidal flooding (Taylor Engineering, Inc. 2019). Despite the success of these implemented resilience projects, securing funds for the design, implementation, and maintenance emerged as a persistent challenge. The City continues to face challenges in obtaining adequate funding to support efforts and implement future projects. Much of the funding available to them for coastal adaptation is for planning grants or is time-sensitive (e.g., state or federal funding that must be spent down in a year). There is a need for multi-year funding for permitting and engineering design. As part of its Adaptation Plan update in 2019, the City created a **summary of external funding alternatives**.[13]

[12] Lowe L. 2020. October 1. Personal communication [Personal interview].

[13] Austin M. 2020. February 3. Personal communication [Personal interview].

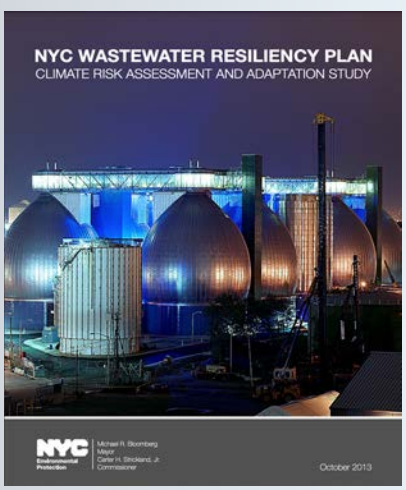
Consider the cost of inaction when making the business case for adaptation.

How much would it cost if adaptation strategies were not implemented? What would this mean for local economic activity and how can this impact be quantified? At a utility, what is the cost of inaction as an asset or system becomes more vulnerable to sea level rise over the course of its useful service life?

In 2012, the **Cedar Key Water and Sewer District** (CKWSD) experienced first-hand the cost of inaction to implement adaptation strategies. This small groundwater-dependent coastal water utility in Florida experienced a saltwater intrusion event that led to the utility imposing a residential drinking water ban. The treatment plant's existing units at the time were unable to desalinate the incoming groundwater. The utility considered importing water from 22 miles away but deemed this plan unfeasible given the time and costs required. Recurring costs associated with renting reverse osmosis (RO) units persuaded the CKWSD to take action and retrofit the treatment plant to support desalination and purchase two RO units for the plant. For CKWSD, the cost of inaction would have been greater in the long-run than the cost of implementing adaptation strategies now (i.e., purchasing its own RO units and implementing retrofits). Capital costs were covered through federal and state grants, and user rates were raised to support operational costs (Saetta et al. 2015).

Conduct cost-benefit and alternative analyses that consider climate change and equity or consider alternative frameworks to guide investments and capital planning.

Cost-benefit analyses and alternatives analysis are intended to help align priorities, understand what is feasible, and better guide investments. However, traditional cost-benefit analysis scoring measures usually do not consider equity concerns or incorporate the value of other social and/or environmental resources. Instead, they focus primarily on financial metrics, leading to a bias for areas with high property values and excluding under-resourced or underfunded communities. Revised scoring measures that expand the definition of "benefit," (e.g., Triple-bottom Line Cost Benefit Analysis) and assessments that consider costs against a changing risk profile due to climate change can help address the limitation of traditional analyses and prioritize equitable solutions.



Credit: New York City Department of Environmental Protection

New York City, New York, is addressing sea level rise through **Climate Resiliency Design Guidelines**, retrofitting, and resiliency plans. New York City's Climate Resiliency Design Guidelines provide instructions on how to make assets more resilient to future climate risks, depending on the asset type, location, useful life, and climate hazard. While the cost of implementing design guideline requirements is often absorbed in the overall costs for new projects, retrofitting existing infrastructure can be costly and difficult to prioritize. To address this challenge, the City conducts cost-benefit analyses to make informed decisions about which adaptation strategies will have the highest impact. The New York City Department of Environmental Protection's NYC **Wastewater Resiliency Plan** lays out details to harden wastewater treatment plants against storm surge by evaluating the risk of each asset, future climate projections, and the adaptation options available. The plan has been highly successful in upgrading the wastewater infrastructure most at risk from storm surge. In addition, the City is increasing public outreach to better communicate the risks from flooding and developed stormwater resiliency maps that identify areas vulnerable to flooding from heavy rain events compounded by sea level rise.[14]

[14] Kimball N., Cohn A., Cashman M. 2020. September 16. Personal communication [Personal interview].

New York City, New York is using the **Envision framework**, which helps decision-makers consider specific criteria (e.g., "expected useful life")[15] and prioritize cost-effective, long-term infrastructure investments. The framework uses a rating system with 64 indicator credits in 5 broad categories (e.g., quality of life, leadership, resource allocation, the natural world, and climate and resilience) to assess and ultimately improve the sustainability, resilience, and equity of infrastructure projects in the city (Institute for Sustainable Infrastructure 2018).

Factor maintenance costs of engineered solutions into strategic decision-making.

It is critical to consider both upfront costs for design and construction and long-term maintenance costs of infrastructure/engineered solutions. In general, significant capital investment is required for the maintenance of water infrastructure adaptation solutions (Azevedo de Almeida & Mostafavi 2016). Hard infrastructure (i.e., seawalls) requires particularly high maintenance costs and may also exacerbate erosion problems, thereby requiring continual reinvestment (Donner & Webber 2014).

Invest in a regional approach rather than individual projects.

Creating a holistic suite of projects in which to invest helps to spread risk and cost across a wider geographic area and set of resources (e.g., funding, time, materials). This will also help to ensure that investments reflect how a singular project promotes or detracts from regional sea level rise resilience efforts.

The Florida Water and Climate Alliance (FloridaWCA) is a conglomeration of stakeholders from municipalities, water management districts, public utilities, and academia in Florida. While this partnership of science stakeholders formed on a voluntary basis without a budget, they were able to make a value case for regional coordination and secured funding from multiple sources to advance the co-production of research and planning. Between 2010 – 2020, FloridaWCA received funding through the Sectoral Applications Research Program of the National Oceanic and Atmospheric Administration (NOAA) Climate Office, National Aeronautics and Space Administration (NASA), the Southeast Climate Adaptation Science Center, Tampa Bay Water, and Peace River Manasota Regional Water Supply Authority. Funds were used to enhance regional understanding of climate change impacts through various activities, including workshops, webinars, and research projects (FloridaWCA 2022). FloridaWCA has been instrumental in increasing coordination, decision support, and resource planning among the water sector in the region. FloridaWCA learned that "...the careful design of such engagement can strengthen the capacity of organizations...", particularly for operational and long-term water resource planning and management (Mirsa et al. 2021, pg. E379). FloridaWCA is an example of a successful regional partnership and plans to continue to grow as an organization, moving further toward the implementation of adaptation strategies.

[15] Kimball N., Cohn A., Cashman M. 2020. September 16. Personal communication [Personal interview].

Leverage funds for purchasing land where ownership issues prevent action.

Privately owned coastal properties are not only at extreme risk from storm surge but can prevent meaningful adaptation of the coastline to protect the wider community. One solution that both moves people out of harm's way and allows for future coastline adaptation is for municipalities to buy coastal land at risk from sea level rise and storm surge so that it can serve as a buffer to upland communities. Buyouts for properties in a highly desirable and highly valued coastal neighborhood are often a challenging and politically charged endeavor. This strategy is not likely to be led by a water utility, but support for managed retreat strategies may be important because it may be the most viable option to protect human life and infrastructure investments in the long term.

The New Jersey Department of Environmental Protection's **Blue Acres Program** was initiated in 1995 as a way for the state to acquire land in flood-prone areas, particularly those that have been damaged by storms or have the potential to serve as a protective buffer to minimize flooding in nearby upland properties. The program expanded in 2012 after Superstorm Sandy severely damaged many homes and communities along New Jersey's coast and floodways. The state sought out properties that were damaged during Superstorm Sandy, as well as those that could increase the connectivity of previously acquired parcels. Once acquired through the program, the properties remain conserved as open green space into perpetuity, and the land is maintained by local municipalities and serves local communities by providing protection from flooding and space for recreation. Overall, the program has acquired over 700 properties in 20 municipalities through buyouts. These buyouts are made possible through a combination of funding from FEMA, the U.S. Department of Housing and Urban Development, and a portion of New Jersey's state corporate business tax (NJDEP 2021).

Develop a dedicated funding source for adaptation and resilience projects.

Funding constraints are one of the most frequently cited reasons for inaction on climate change. While federal funds to support infrastructure resilience are becoming more available to municipalities through the Infrastructure Investment and Jobs Act, many grants or funding sources are restrictive in terms of sustained funding over time to maintain projects. Building a dedicated climate adaptation funding source within a water utility or city (through taxes and/or fees) can guarantee long-term adaptation funding stability for the utility over time but also garner more climate change awareness in the community at large.

As a means to address the common issue of lack of dedicated funding for adaptation-related projects, the Town of **Corte Madera, California**, has a **Measure F sales tax** that provides unrestricted general revenue for purposes such as addressing flooding and sea level rise, roadway maintenance and upgrades, and disaster preparedness and has been used to improve flood control infrastructure in the town. The Measure F sales tax extended Corte Madera's existing sales tax rate from 0.5 cent to 0.75 cent and repealed the Town's existing storm drainage special tax (a $98 annual charge per residential unit or 1,000 commercial square feet). This means that residents and businesses decrease their annual bills by $98 and the Town will shift revenue generation from the storm drainage tax (~$600,000/year) to the new sales tax measure (0.75 cent rate) that could provide $3.5 million for general revenue purposes per year. Since the revenue generated from Measure F can be used for any capital improvement projects as unrestricted general revenue, local storm drainage systems will not suffer from the loss of the storm drainage special tax. In fact, the increase in revenue from Measure F opens up the possibility for more projects, repairs, and improvements. The implementation of this financial revenue stream has funded repairs to the Golden Hind Pump Station, Marina Village levee enhancement, and repair and installation improvements to storm drain pipelines. Future funds will go toward the implementation of the Shorebird Marsh Pump Station improvements, including replacing grates, grate frames, and a pump enclosure. The funds will also go toward the town's Climate Adaptation Plan (Town of Corte Madera 2018).

The **City of Virginia Beach, Virginia,** is using stormwater utility fees and General Obligation Bonds to fund stormwater system maintenance capital improvement projects in the city. A recent capital improvement plan (CIP) includes the installation of a weir and pump station and reforestation of the recently constructed neighborhood of Ashville Park. The City's Parks & Recreation's Park and Landscape Services' staff and a team of volunteers planted 800 trees to help remediate excessive stormwater flooding in the area. The neighborhood is at risk of flooding due to undersized storm drainage pipes and experienced a major flooding event in 2016 during Hurricane Matthew, but since the implementation of the project, the improvements have helped to reduce flooding. As part of its CIP plan, the City planned on increasing the stormwater utility fee to fund additional projects, but in November 2021, Virginia Beach residents voted to approve a Stormwater Bond Referendum, in the amount of $567 million, for Phase 1 of drainage improvement projects. As a part of the referendum, the City Council froze the stormwater utility fee, barring additional increases for 5 years. The City also offers fee reduction incentives for commercial properties that reduce the area of impervious surfaces on their properties or install green infrastructure. Additional information on these projects are detailed in the **City's Sea Level Wise program and Adaptation Strategy document**.[16]

Become familiar with funding options available for adaptation and hazard mitigation projects. State and federal governments provide a range of grants and loans that can be used for project scoping or implementation, such as the Clean Water State Revolving Fund, the NOAA Coastal Zone Management Program, or FEMA's Building Resilient Infrastructure and Communities (BRIC) program. In addition to financial awards, some programs provide technical assistance to support future grant application development.

Many federal agencies offer grants and programs to fund resiliency and adaptation projects, and an influx of funding will be available to water utilities through the Infrastructure Investment and Jobs Act in the coming years (2022–2026). While it sometimes is difficult and resource-intensive to apply for federal grants, dedicated time and effort can pay off if the proper grant is identified and a strong case can be made for the value of the project. It is common for water utilities to rely on consultants to help navigate the grant funding process, from identification of funding opportunities, to grant application development, to submission. However, if soliciting help from consultants is not feasible, there are several federal technical assistance programs that can provide support for application needs. For example, FEMA's BRIC program offers a Direct Technical Assistance that can support communities that may not have in-house capacity for applying for BRIC grants. Make sure that your adaptation project is included in your local hazard mitigation plan, because this is often a requirement for federal grants.

One of the largest barriers to adaptation action for the **Hampton Roads Sanitary District (HRSD) in Hampton Roads, Virginia,** is the limited resources available to conduct research on sea level rise impacts to wastewater utilities and the measures needed to address such impacts. These technical issues make it difficult to convince stakeholders that enacting sea level rise and flooding adaptation measures is urgent. HRSD's work is restricted by data limitations, uncertainty of future impacts, and finding the proper downscaling of climate models. **The HRSD SWIFT (Sustainable Water Initiative for Tomorrow) project** is helping the District to address some of these barriers by facilitating a climate change vulnerability and future planning study. In addition, SWIFT was created to produce a sustainable source of groundwater while addressing challenges such as sea level rise and saltwater intrusion. HRSD is funding SWIFT through a $700 million loan provided by the U.S. Environmental Protection Agency (EPA) Water Infrastructure Finance and Innovation Act (WIFIA) and up to $500 million in funds from the State Revolving Loan Program (EPA 2021).

[16] Utterback T. 2020. September 11. Personal communication [Personal interview].

Credit: Hampton Roads Sanitary District

SWIFT a program consisting of 25 individual projects, with multiple projects starting now and others being initiated through 2030. The WIFIA funding is flexible in that HRSD can draw on the funds as needed and do not have to start paying interest until they begin drawing from them. This allows HRSD to leverage their state clean water revolving fund and use WIFIA to fund projects in tandem. In this way, HRSD can use more short-term financing to save money down the line. The EPA loan will not only sustain the SWIFT project, but also will create over 1,400 new jobs in the region and save taxpayers about $300 million in financing. These funds will cover about 70 percent of the cost for the project's initial phase. Without this federal funding, HRSD would likely have to depend on bond financing, raise rates, and scale back projects. The project's development was prompted by the consent decree that requires HRSD and Hampton Roads localities to eliminate all sanitary sewer overflows, prohibit unauthorized discharges from sewage treatment plants, and develop a Regional Wet Weather Management Plan (HRSD 2022). The SWIFT project will inject treated wastewater into the Potomac deep water aquifer, which can protect groundwater from saltwater intrusion and help to reduce the rate that the land is sinking in the area. The innovative SWIFT project has been a successful way to allocate existing funds toward resilience, thereby building technical actions in eastern Virginia.[17 18]

[17] McFarlane B. 2020. October 21. Personal communication [Personal interview].

[18] Girardi, E. 2022. August 22. Personal communication [Personal interview].

tech·ni·cal / ˈteknək(ə)l /

1. belonging or pertaining to a skill in a specific field
2. skilled in or familiar in a practical way with a particular art, trade, etc.
3. peculiar to or characteristic of a particular art, science, profession, trade, etc.

TECHNICAL

Technical barriers are factors that limit the ***availability*** and ***feasibility*** of adaptation implementation options. Technical barriers may include a lack of staff capacity or technical ability to work through the various adaptation phases. For example, barriers can relate to working with climate projections, assessing risk, dealing with uncertainty, or developing adaptation solutions; a lack of confidence/agreement in climate model projections; limited local information and data deficiencies; a lack of resources (beyond financial) to develop tools and make climate information actionable; and a lack of expertise in adaptive risk management strategies.

While there is nearly unanimous consensus that the climate is changing, there is uncertainty around the scale, direction, and characteristics of some of these changes. Climate stationarity can no longer be assumed, and even with quickly advancing science and modeling techniques, there will never be precise forecasts for climate impacts. This brings a new level of uncertainty that requires adopting unfamiliar engineering practices and risk management approaches. These emerging engineering and management approaches—such as developing an adaptive management plan—may not be supported or understood. Adaptation solutions may be technically challenging to design and implement due to their complexity, large scale, and sometimes unfamiliar nature to the planning and design staff within an organization (e.g., new design approaches used to address a challenge that climate change introduces). Novel skills, expertise, and new technologies may be required.

LEADING PRACTICES

Pay attention to the cumulative effects of climate-related stressors (e.g., sea level rise, precipitation and storm intensity, drought) and interactions with non-climate stressors (e.g., social vulnerability, development pressures).

Climate stressors are not mutually exclusive and may all happen simultaneously; for example, sea level rise will exacerbate inundation during storms. Non-climate stressors may also amplify vulnerability to sea level rise; for example, shoreline hardening in one location can hinder sediment accretion and increase erosion rates and infrastructure damage in another. Planning across stressors is important but also complicates decision-making because multiple partners, agencies, and potentially cities need to be involved in order to effectively respond.

Mainstream the iterative nature of adaptation into all decision-making processes and use flexible and adaptive risk management approaches (e.g., dynamic adaptation policy pathways).

Climate change, specifically non-stationarity, requires that all long-term planning efforts remain flexible enough for course corrections. Comprehensive plans and resilience standards cannot be a "one-and-done" activity and must include updates that balance the need for consistent information and numbers for design with staying up to date on the latest climate science and projections. One way to build flexibility into plans and programs is to employ adaptive management strategies, such as flexible adaptation pathways or dynamic adaptation policy pathways. These approaches provide adaptive decision-making tools that can account for a changing risk profile over time. They help users consider future conditions under which an adaptation solution—be it a policy or project—will fail to reduce risk. These approaches recognize triggers for action (e.g., sea level rise trends reach a certain point or global temperature thresholds are surpassed) and identify alternative adaptation pathways to reduce risks once thresholds or tipping points occur. Appendix C provides a comprehensive review of the adaptation pathway approaches available and how they can be applied to the water sector.

> The Thames Barrier system in **London, United Kingdom,** was designed to ameliorate the impacts of flooding and sea level rise on the city. The Thames Estuary 2100 plan considers incremental adaptation measures over short (to 2034), medium (through 2069), and long (from 2070) time frames. The plan "allows for flexibility on the timing of introduction of different options and interventions, and the ability of the plan to change between options, based on the monitoring program. Detailed guidance is provided on how the recommendations contained in the plan should be applied in the event that more extreme change is realized; for example, if it becomes necessary to divert to an alternative adaptation pathway. This guidance also shows how lead times for major interventions need to take account of any such changes and is underpinned both by the identification of key decision points and by the inclusion of the monitoring and review cycle (Innocenti & Albrito 2011)" (Goodhew 2014, pg. 242).

Leverage existing tools where possible to support decision-making. A lack of technical analysis of future conditions should not equate to inaction.

Adaptation planners are often asked to make decisions based on imperfect guidance and uncertain scientific information. For example, while NOAA provides a great service with their **Sea Level Rise Viewer tool**, higher resolution flood maps with more information (e.g., storm surge) are often necessary for making local decisions, such as where to place infrastructure and how high to build it. Developing models and technical assessments using climate information can be costly and resource-intensive. If local resources and assessments are not available, try to leverage or creatively modify existing tools (many tools have been developed by regional, state, and federal governments, such as the **U.S. Climate Resilience Toolkit**, and examples of these can be found in Appendix A of this guide). For example, while FEMA's Flood Insurance Rate Maps do not include future conditions like sea level rise, they are still a useful tool for assessing flood risk. Consider adding a safety factor to account for sea level rise in addition to the base flood elevation that FEMA provides, or opt to use the 500-year flood extent and elevations as a proxy for future conditions with higher sea levels and more intense precipitation.

Unified sea level rise projections for a region, municipality, or city ensure consistency in adaptation planning.

Using consistent sea level rise projections, whether across an organization, sector, city, county, or region, is important to ensure all parties are operating off the same baseline information. Ensuring a common understanding based on centralized information can increase decision-making transparency, streamline the planning process, and prevent maladaptation and unintended consequences down the road.

Central District Watewater Treatment Plant Facilities
Image Courtesy of Miami-Dade County

Southeast Florida's counties and municipalities use regionally **unified sea level rise projections** developed by the Southeast Florida Regional Climate Compact (SEFRCC). The projections are updated every 5 years and are intended to inform design and construction standards, which allows county and municipality agencies to be consistent across planning, communications, legislation, and advocacy. **Miami-Dade County** uses these unified sea level rise projections to prioritize vulnerable facilities; as a result, the City decided to elevate the Central District Wastewater Treatment Plant facilities on Virginia Key to 21 feet (Coffman & Arik 2020). The amount of elevation was determined by the County by using the following formula for retrofitting of existing wastewater treatment plant facility assets: FEMA BFE + 3-feet sea level rise (2011 SEFRCC unified projections) + 2-feet freeboard (ASCE Standard 24-05/2010 FBC Category IV) + 48 inches safety factor (NOAA High projection for 50-year planning horizon) (Miami-Dade County 2021).

Nature-based solutions to sea level rise often yield multiple benefits to the community and the environment. Co-benefits not only enhance the community, but can also appeal to funders and create more value for the investment.

Nature-based solutions, as opposed to traditional grey infrastructure solutions, use natural features or processes to promote adaptation and resilience. Nature-based solutions also tend to generate multiple benefits in addition to flood protection, such as ecological restoration, increased greenspace, and reduced urban heat islands, among others. Any project that creates multiple benefits for the community and the utility (including nature-based and traditional engineered solutions) often appeals to funders. When seeking funding, utilities should consider highlighting the additional benefits which can sometimes allow for layering of funding sources.

Cecchetti et al. (2020) evaluated the use of a horizontal levee to reduce flooding from storm surge, provide space for wetland migration as sea levels rise, and remove contaminants from treated water discharged into the ocean. The authors designed an experimental horizontal levee in **San Lorenzo, California**, to treat secondary effluent from the **Oro Loma Sanitary District's** wastewater treatment plant and evaluate performance over 2 years to identify levee operating conditions that may be suitable in light of sea level rise. The results indicated that horizontal levees can achieve multiple benefits from increased coastal resilience to sea level rise to significant removal of wastewater-derived contaminants (e.g., nutrients, pharmaceuticals, F+ coliphage) and may support potable water reuse.

Kirshen et al. (2020) evaluated the technological and economic feasibility of a range of adaptation options to address coastal flooding in **Boston, Massachusetts**, including physical harbor-wide barriers, elevated infrastructure along the shoreline, and nature-based solutions. The study found that the harbor barriers were associated with several limitations, while elevating infrastructure and using nature-based options yielded multiple benefits (e.g., flood protection, minimal environmental impact, more flexibility) more quickly and for less money.

Look for innovative engineered ways to "make room for water."

In places where it is difficult to completely prevent flooding, accepting that flooding will occur and finding innovative ways to accommodate extra water can reduce flooding risks and resulting damage. Historically, at least in the last 100 years, humans have tried to prevent flooding by engineering hard structures to keep water out (e.g., levees or seawalls implemented by USACE). In recent years, especially in places vulnerable to sea level rise, there has been a paradigm shift, and communities are now finding ways to live with water and turning to approaches that let water in. The combination of urban design strategies (e.g., parks designed to temporarily take on flood waters), nature-based solutions, and gray infrastructure can be used to create space for flood waters.

Retrofit existing critical infrastructure to accommodate rising water levels.

While often challenging and costly, retrofitting existing infrastructure is an important way to build resilience into vulnerable assets and systems. Retrofitting can prevent service interruptions during flood events and should be prioritized based on the flood risk and the importance of the asset (e.g., consider the criticality, replacement cost, population served). Retrofits may include raising electrical equipment out of the flood zone, moving an asset to a less vulnerable location, floodproofing buildings and equipment, enlarging parts of the stormwater system, and adding pumps to convey flood waters or add redundancy.

The **City of Portsmouth, New Hampshire, Public Work Department** is creating ways to accommodate storm surge-induced flooding and rising sea levels. The city contains ~100 miles of sewer pipes and ~65 miles of storm drain pipes in its separate sewer area but sections of the city are still served by a combined sewer. Like many older cities in the U.S., parts of Portsmouth's storm and sewer system are undersized and reaching the end of their useful lifespans—some pipes are nearly 100 years old. When they experience storm surge or extreme weather events with heavy precipitation in combination with high tides, it is hard for their stormwater system to drain which can lead to surface flooding. Additionally, their combined sewer system can cause basement backups and overflow into nearby water bodies during these events. The City has worked for decades to address these issues. They successfully reduced flooding, combined sewer overflow events, and sewer backups into basements by (1) separating parts of their combined sewer system, (2) building additional upstream outfalls to reduce the amount of water backing up further down in the system, and (3) by rerouting some storm pipes to locations where they can better discharge. The City has real-time monitoring data from their sewer overflow systems that show improvement in decreasing flooding impacts during storm and storm surge events.[19]

[19] Goetz B. 2021. December 15. Personal communication [Personal interview].

The **City of Anacortes, Washington,** redesigned their water treatment plant to address flooding and saltwater intrusion. The redesign and construction included raising critical electrical equipment out of the (current) 100-year flood elevation level; installing ring dikes and pumps; utilizing water-proofing techniques below the ring dike elevation (40 feet); and developing a more effective sediment removal process (EPA 2022; SC2 2015).

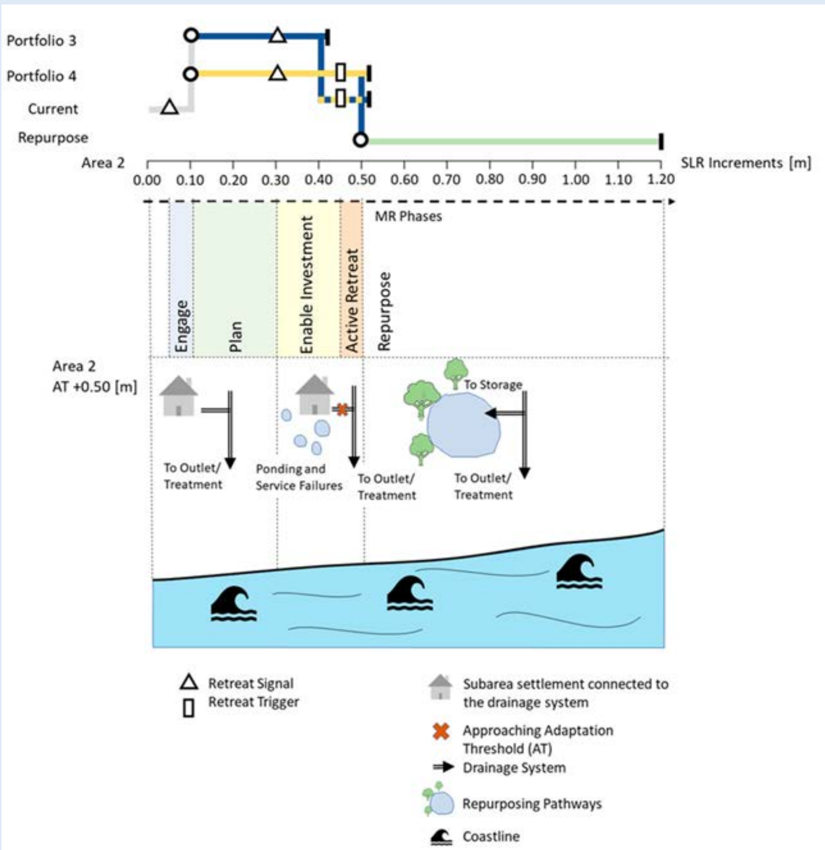
While adaptive management approaches are necessary for dealing with the uncertainty associated with climate change, longstanding planning principles and tools (e.g., land use planning or marine spatial planning) can still be useful (or modified) to better understand risk and identify adaptation solutions.

Traditional planning principles are a good place to start and can serve you well when developing sea level rise adaptation strategies; however, they do not typically allow for much flexibility in the long-term planning process. Finding ways to reimagine longstanding planning principles and standardize an adaptation approach that works for your utility can be beneficial for addressing the deep uncertainty associated with sea level rise. Beyond traditional planning principles, new adaptive management strategies have been developed to manage climate uncertainty and build in flexibility, such as the Dynamic Adaptive Policy Pathways (DAPP) approach (Haasnoot et al. 2013). DAPP is an adaptive management strategy that allows planners to develop different future pathways that can be switched between as conditions change or certain thresholds are met or exceeded.

The **City of Norfolk, Virginia,** has developed a plan that prioritizes zones within the city for adaptation action based on future and present threats from climate change as well as economic potential and number of assets in an area. Four types of zones were created and four different approaches were developed to address sea level rise and flooding in the city, one for each zone. This planning and prioritization of actions has allowed the City to customize implementation efforts and information outreach based on each zone's specific characteristics and needs. In addition, due to risk analyses and "priority zone" planning efforts, the City has been able to connect adaptation planning with future plans for infrastructure development within the city and infrastructure hardening projects with USACE. These efforts can help the City mitigate future technical barriers in planning by providing clear options and priorities. Adaptation actions considered or implemented by the City in the priority zones include expanding flood protection systems and raising the sea wall, developing new zoning ordinances and resilience requirements, investing in transportation infrastructure, and community outreach.[20]

[20] Shea P. 2020. August 19. Personal communication [Personal interview].

National assessments in New Zealand have identified stormwater and wastewater infrastructure as more exposed to sea level rise than any other kind of infrastructure (Paulik et al. 2020). It is anticipated that the slow incremental rise of the sea, as opposed to flooding caused by extreme episodic events, will have the largest detrimental impact on drainage systems. Sea level rise makes it harder for these systems to discharge and subsurface drainage pipes could be infiltrated by groundwater as it ascends with sea level rise. In **Hutt City, an area near Wellington, New Zealand**, Dynamic Adaptation Policy Pathways (DAPP) were used to explore whether the mostly gravity-fed stormwater and wastewater networks can be adapted over time to retain Levels of Service, or whether full or partial retreat is the only viable option in the future (Kool et al. 2020). Through interactive workshops, stakeholders identified critical thresholds (e.g., 0.3 m of sea level rise) by stress testing the drainage system and determining when it would no longer be able to provide the necessary level of service (quantitative) or lead to unacceptable conditions (qualitative). Different thresholds were developed depending on the asset type (e.g., subsurface pipe or pumping station). They then developed aligned location-specific adaptation actions to avoid reaching that threshold or planned retreat strategies that would be initiated if reaching the threshold was unavoidable. Strategies to adapt generally involved increasing surface detention systems to keep water out of the drainage system in the first place (e.g., water-sensitive urban design).



Comprehensive planned retreat strategies include several pathways for action and consider the community's coping capacity. Different phases of retreat and approaches for implementation (e.g., community-led versus service removal) were identified with an assessment of pathway conflicts and synergies. Signals or triggers using observations and monitoring are a key part of understanding when a threshold is approaching. The lead time for implementing an adaptation strategy or retreat strategy must also be considered as pathways are developed. More on adaptation pathways can be found in Appendix C of this guide.

Credit: Kool R, Lawrence J, Drews M, Bell R. 2020. Preparing for Sea-Level Rise through Adaptive Managed Retreat of a New Zealand Stormwater and Wastewater Network"Infrastructures5, no. 11: 92. https://doi.org/10.3390/infrastructures5110092

Develop standards and tools to help with decision-making and alternatives evaluation.

Invest time into developing standardized tools that can guide adaptation decision-making and prioritize strategies that will best serve your utility. Implementing a standardized and transparent approach for future planning decisions allows for utilities to identify and weight top criteria for project consideration that may be unique to their geographic area or governance structure.

Image courtesy of Miami-Dade County

Miami-Dade County Water and Sewer Department (MDWSD) developed a decision support matrix to prioritize adaptation options to address the impacts of sea level rise. The matrix allows MDWSD to compare the costs, risks, and operational impacts that alternative adaptation strategies will have on specific assets and to make climate-informed design and investment decisions. This process allows for flexibility in planning future actions and pairs with MDWSD's Design Guidebooks that were developed for wastewater treatment plants and pump stations. . The combination of these two tools will help design engineers to plan for and understand impacts, the timing of events, and the necessary elevation of assets based on future sea level rise projections.[21]

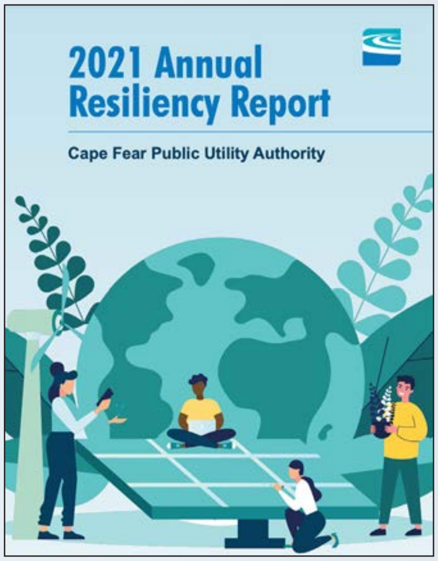
Lack of "actionable" information and tools that can be used directly in assessments and studies addressing climate change can often be a barrier for those trying to take adaptation action. The **Philadelphia Water Department (PWD)** has addressed this challenge by developing several products and tools to better understand and address sea level rise adaptation for water utilities. For example, PWD has produced estimated future tidal data and storm surge elevations for use in project planning and design; a customized Geographic Information System (GIS) tool that estimates and illustrates the timing and extent of future coastal flooding and enables PWD to screen existing assets for future flood exposure; a Design Flood Elevation for new capital projects that incorporates sea level rise projections and goes above local floodplain regulatory requirements; an Excel-based tool that uses different sea level rise scenarios and provides estimates for the changing probability of flooding through the end of the century for any input elevation; and written guidance on how to apply adaptive management principles to address sea level rise uncertainty.[22]

[21] Griner D. & Yoder D. 2020. September 15. Personal communication [Personal interview].

[22] Rockwell J. & Anbessie T. 2020. November 16. Personal communication [WUCA member questionnaire].

Find creative ways to augment staff capacity.

A water utility can face challenges surrounding the prioritization of tasks and developing new work to address climate change when there already exist many other "fires" to put out, especially if they are driven by regulations. To build more internal capacity for resiliency work, interns and students can be used to share adaptation workload. Furthermore, partnerships with local organizations or academic institutions can set up data, analysis, and general knowledge sharing conduits that may aid the adaptation planning and assessment processes and avoid duplication of efforts.



Credit: Cape Fear Public Utility Authority

Cape Fear Public Utility Authority (CFPUA) in Wilmington, North Carolina, developed floodplain maps for their pump stations for 100- and 500-year flood events through a collaboration with the EPA and integrated some of the findings from the resulting report in its CIP. CFPUA also wanted to document where adaptation measures (e.g., elevating platforms) were put in place as well as collect pump station control elevation data. CFPUA acquired all the necessary equipment, but due to lack of staff capacity and interest at the time, CFPUA was unable to obtain monitoring and evaluation data. To address this challenge, CFPUA has used interns and local partnerships to collect data that aided in the creation of an **interactive map** displaying flood resilience and CFPUA assets and to develop a **source water protection plan** and **resiliency report**. CFPUA staff working on climate change adaptation emphasize the importance of strengthening and maintaining relationships with CFPUA board members, city and county governments, local universities, and citizen groups These collaborations, as well as buy-in from CFPUA's Environmental Group, sustainability committee, financial director, and other local partners, has not only led to the creation of the source water protection plan and resiliency report but also progress toward adaptation implementation and unified support for adaptation action. From CFPUA's perspective, finding common ground and engaging local partners can lead to alignment in priorities and marrying of funding that can be a catalyst for building resilience from both an environmental and social perspective.[23]

[23] Eckert B., Severt E., Tremblay E. 2021 December 16. Personal communication [Personal interview]

so·cial / ˈsōSH(ə)l / • **cul·tur·al** / ˈkəlCH(ə)rəl /

1. of or relating to the life, welfare, and relations of human beings in a community
2. the behaviors and beliefs characteristic of a particular group of people, as a social, ethnic, profession, or age group
3. the shared beliefs, behaviors, or social environment connected with a particular aspect of society

SOCIAL / CULTURAL

Social and cultural barriers relate to behavioral and non-material issues, such as a lack of understanding; political polarization; resistance to change; apathy or fatigue; the tendency to discount future benefits; and feelings of empowerment, identity, and perception. These barriers tend to revolve around an inability or unwillingness to understand and prioritize climate change science and risks. Social/cultural barriers may also involve fear, uncertainty, denial, and apathy and their effect on decision-making or project prioritization. Additionally, there are specific psychological and political effects at play, including short election cycles, the tendency for short-term thinking rather than strategic long-term planning, and one's alignment with family values or political affiliation. As a result, decisions may not be based on facts or logic, but rather on aligning with the beliefs and convictions of family members, neighbors, community, and political party.

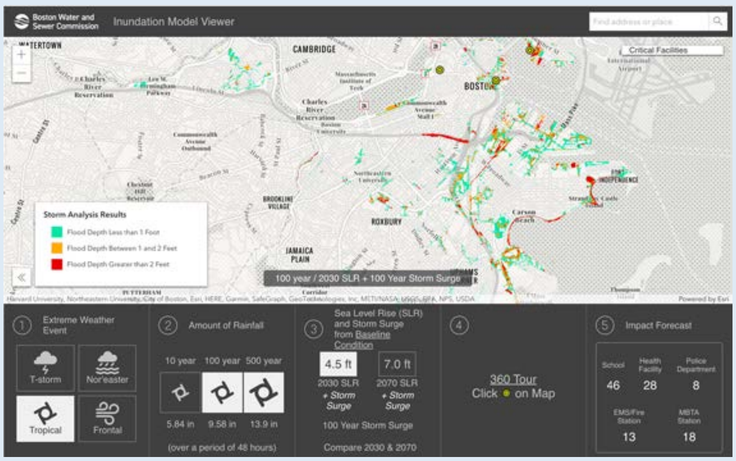
Effective and strategic climate communication and education are essential tools to help address these types of social/cultural barriers. Communication strategies will need to be developed to target different audiences (e.g., internal staff versus board members versus residents), and any adaptation solutions or strategies that impact residents should be developed, planned, and implemented by engaging with and seeking input from community members.

Social/cultural barriers can be difficult to overcome; it can take years of thoughtful, strategic communication and planning before a change is detected or progress is made. While it is beyond the scope of this document to provide extensive tips on communication and strategies to shift perspectives, the leading practices provided here include insights and several tangible examples from utilities that have made steps in the right direction.

LEADING PRACTICES

Strategically use visuals that evoke a personal connection to a lived or simulated experience to encourage engagement from community members and those in leadership or decision-making roles.

Strong visualization tools can make the connections for people between sea level rise projections, consequences, and the viability of potential adaptation responses. Communications tools, such as current and future inundation maps, can provide visuals that resonate with the public and can encourage investment from those with decision-making power.



Credit: Boston Water and Sewer Commission

The **Boston Water and Sewer Commission (BWSC)** developed **the City of Boston Inundation Model Viewer** as an outreach tool to gain support for adaptation action from the public and City officials. This dynamic tool allows users to simulate what Boston would look like under different storm surge, rainfall, and sea level rise scenarios in powerful 360°, three-dimensional (3-D) images. Users get a realistic sense of the potential destruction from different flood scenarios, which helps communicate the risk far better than a 2-D inundation map.

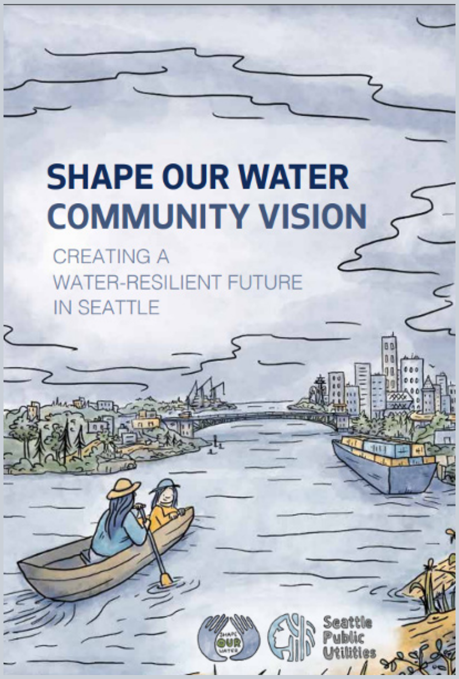
Strong visualization tools can connect a community's lived experience to projections of the impacts of climate change and potential effectiveness of adaptation options. A recent study from Stempel et al. (2021) demonstrates the importance of using different types of visualizations to communicate about sea level rise risk and investigates which tools are most effective for engaging stakeholders and inciting action. The study summarizes a survey of stakeholders concerning the saliency and concern for sea level rise and perceived risk from storm surge in **Portsmouth, Rhode Island**. Results indicate that there may be a benefit in separating storm surge and sea level rise visualizations to increase the effectiveness of sea level rise-only visualizations in inciting public concern and action. When it came to visuals incorporating storm surge, participants compared their lived experience with "lesser storms" to the more destructive hurricanes experienced in the southeastern United States. The participants' first-hand experience with extreme weather events (i.e., hurricanes and resulting storm surge) led them to discount the risk of such events in their area. However, when participants viewed sea level rise-only visualizations, they connected projected scenarios with issues they are already experiencing in their lives due to rising waters (e.g., failing storm drains). The near-term sea level rise-only scenarios were less likely to be dismissed by survey participants and may be effective for increasing adaptation engagement and investment by better relating to what participants already know and experience (Stempel et al. 2021).

Through the **Blue Line Project** in **Norfolk, Virginia**, Hutton and Allen (2021) engaged local communities in determining what types of visualizations (maps versus photographs) were effective in increasing risk perception and contribute to the selection of adaptation strategies. They found that a balance of photographs and maps (essentially a balance of more personal versus more scientific visualizations) were most effective against their criteria, and the likelihood of taking action increased with combinations of both types of visualizations. Hutton and Allen (2021) suggest that these types of tools can help to address some social and communication barriers and may motivate government support for planning.

Credit: Aileen Devlin, Courtesy of Virginia Sea Grant, https://digitalcommons.odu.edu/watersrising-images/11/

Adaptation strategies, projects, or policies that impact residents should be co-produced with community members from the outset. This ensures that the unique needs, cumulative impacts, priorities and characteristics of a community are taken into account and underpin decisions that can maximize economic, health, and quality of life benefits.

Sea level rise is one of many challenges coastal cities face and it is interconnected with other environmental, social, and economic challenges such as seismic risks, racial injustices, population growth, and affordability. As stewards for the environment and community health, utilities must consider this web of challenges when planning and designing projects and programs. When utilities invest in infrastructure for climate change, they also have an opportunity to promote positive health outcomes, wealth building and workforce development opportunities and partnerships. Traditionally, projects have been brought to community members and key stakeholders late in the planning process, fundamentally limiting the amount of input communities have on projects that may significantly affect their neighborhood. To develop infrastructure that delivers multiple benefits to communities today and in the future, many utilities and cities are shifting how projects and programs are planned and designed by moving towards a collaborative co-production process that includes communities and cross sector partners at the start of (and throughout) the planning process to ensure that the solutions adopted fit the unique needs of each community. Real, compensated collaboration with communities and stakeholders results in projects and programs that better address community priorities and that deliver benefits on many fronts.



Credit: Settle Public Utilities

Seattle Public Utilities (SPU) is planning for future impacts to its drainage and wastewater system in the integrated system planning process, **Shape Our Water**. Shape Our Water is a community-centered plan for Seattle's next 50 years of resilient drainage and wastewater systems. The vision for this project was co-created with community members and key partners. The driving belief behind the engagement process was that when community sets the priorities for change, the utility can ensure that future investments in the drainage and wastewater system bring economic, health, and quality of life benefits to people who have been historically under-served and who lack equal access to resources and opportunity. To reach a broad range of community members and customers in the Seattle, Washington, area, Shape Our Water used a wide array of innovative strategies to engage, participate, and co-create. Informational and educational materials, interactive online maps and walking tours, and multi-day virtual gatherings created a suite of opportunities for people to engage, learn, and contribute—all following current public health guidance at the time for COVID-19 safety. This engagement and visioning process resulted in the **community vision and goals** for Shape Our Water. This provides the foundation for the utility's 50-year infrastructure plan. More information can be found at **www.ShapeOurWater.org**.[24]

Credit: West Seattle Blog photo by Nick Adams

In **Seattle, Washington,** displacement and gentrification of communities are major challenges to equitable adaptation. These challenges are much more pressing for many businesses and residents in Seattle than sea level rise adaptation. There is concern, particularly in Seattle neighborhoods that are still relatively affordable, that capital improvements to protect areas from sea level rise-related coastal flooding will result in increased displacement pressure. SPU is co-leading an effort with help from City, community, and philanthropic partners (e.g., Center for Community Investment, the Duwamish River Cleanup Community Coalition, local housing coalitions, the City of Seattle's Office of Sustainability and Environment, and the Seattle Foundation; Zehner 2019) to develop a Resilience District and a sea level rise adaptation strategy for Seattle's lowest lying neighborhoods. This approach, detailed in **this article**, leads with community resilience through local empowerment, economic development, and adapting to flood risk.[25]

[24] Grodnik-Nagle A. 2020. September. Personal communication [WUCA member questionnaire].

[25] Grodnik-Nagle A. 2020. September. Personal communication [WUCA member questionnaire].

Find ways to connect sea level rise and flood risk to a variety of audiences of diverse backgrounds. Develop communication tools and create messaging and outreach strategies for a variety of audiences.

Different people respond to different messages and means of delivering those messages. Outreach on sea level rise science and adaptation measures should be tailored to best connect with people's values, interests, and areas of expertise (e.g., politicians, real estate developers, and residents). Choose your language and outreach strategies carefully. For example, the term "climate change" will have varied connotations across different groups of people. Consider using more general terms, such as flooding, to connect concepts and adaptation measures to different audiences. A tiered approach is suggested to initiate the development of educational tools, workshops, and collaborations: (1) embed information into existing campaigns; (2) develop new campaigns and work with communication experts and graphic designers on the creation of visuals and tools; and (3) hire a staff member to work specifically on public engagement or use/form relationships with public affairs staff and/or public information officer.

Have patience when building community trust; be prepared for it to take effort and time. Partner with local organizations or faith-based institutions that the community trusts as a way to foster dialog and gain buy-in.

Engaging the public in the adaptation process is important, and building long-term trust with communities is vital for creating sustainable solutions that address specific neighborhood needs. Building trust will take dedicated and sustained effort. Historically, governments have enacted harmful policies that have further marginalized certain communities and groups of people, which has created deep-seated distrust in government agencies. Be prepared (and willing) to work hard to rebuild trust with communities that have been systematically wronged. The transparency and accountability of top-level leadership (e.g., mayors and council members) is critical to repairing relationships. Partnering with respected community groups (e.g., a community group, faith-based organization or trusted local business) can also aid and guide trust-building and open communication. Other ideas to help build relationships and encourage public participation include developing easy-to-understand educational materials; being willing to listen and help address quality of life concerns that may be completely unrelated to your project; and offering childcare, food, and compensation for participation. **Seattle Public Utilities Community Connections** program funds multi-year partnerships with trusted organizations and leaders that serve a variety of ethnic and language groups in Seattle. The goal of this longstanding program is to form deep and sustainable partnerships that increase understanding on the utility side and the community side of priorities, drivers, and context.

FINAL REMARKS

The goal of this document is to identify leading practices to help the water sector move forward and take adaptation action to address sea level rise. While there are many practices presented herein that water utilities can employ on their own—such as raising critical equipment out of the floodplain or making the business case to invest in RO technology—many of the leading practices outlined here require thoughtful coordination with other city departments and stakeholders. In developing this guide and uncovering inspiring examples of implemented adaptation actions from around the country, a fatal flaw in our effort emerged: it is focused on one sector. Piecemeal efforts by one sector may build resilience to a degree, but to successfully adapt in a holistic way, we must start thinking beyond our siloed work environments and coordinate on a scale that has never been seen before.

Another flaw that emerged is the imperfect framing of implementation barriers in four discrete categories; in reality, these barriers are often closely linked and interdependent. For example, a lack of political support may lead to increased financial constraints, and financial constraints might lead to technical limitations. Again, we find that to holistically address sea level rise threats and the broader climate crisis, we need a paradigm shift. While bottom-up efforts can be successful, ultimately, top-down support and a willingness to prioritize planning and projects that address the climate crisis are needed. Therefore, looking at the leading practices to overcome governance barriers may be the best place to start.

While it is clear we need a monumental shift in our thinking about climate change, the small and incremental improvements to improve infrastructure resilience, make staff more prepared, and empower and inform communities do matter—the small changes can sum up to significant impacts. Climate adaptation is an inherently difficult process, and with dedicated effort we can begin pushing past the barriers to create sustainable and equitable water systems and communities. How we begin to accomplish this will vary, but the examples in this guide demonstrate the creative and collaborative steps water utilities nationwide have already taken to achieve this vision.

OVERARCHING THEMES

As utilities undertake adaptation planning and begin the implementation process, we hope the leading practices assembled through this multi-year project provide real-world examples of solutions and success. We would like to conclude by highlighting overarching themes that emerged:

1

Think big and outside the box

As our climate continues to change, we, as water utilities, must continue pushing the boundaries and strive for innovation. The status quo is not adequate. To truly address the magnitude of the climate crisis, we need to think creatively, beyond traditional solutions.

2

Collaborate across siloes with a diverse set of stakeholders

Many of the leading practices highlighted here cannot be implemented by the water sector alone. Strong partnerships with other government agencies, stakeholders, and community members provide a space to include new voices to develop creative, effective, large-scale adaptation projects that address multiple issues and leverage resources.

3

Incorporate flexibility and iteration in your adaptation planning and implementation

Adaptation planning to implementation is not a one-and-done process. With ever-changing information and considerable uncertainty, adaptation strategies must remain flexible and be re-evaluated often. The case studies highlighted in this guide often demonstrate where flexibility in the planning process can pay off in the long run by avoiding over investments. The ability to pivot as new information and resources become available can serve utilities well throughout the adaptation process.

4

Consider all planning and decisions through an equity and environmental justice lens

Flooding hazards and the underlying causes of their disproportionate impact on vulnerable populations pose one of the biggest environmental justice challenges of our time. The climate crisis continues to exacerbate social inequities across our cities and communities, making them inextricably linked. Equitable, co-produced adaptation solutions are vital to ensuring our actions protect—and do not inadvertently harm—the communities we serve. Many of the leading practices in this guide touch upon equity and community engagement, yet it falls short of comprehensively viewing solutions through an equity lens. Going forward, we must shift our thinking to consider water and climate equity in everything we do.

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APPENDICES

A. Adaptation Tools and Documents

The tools and documents found in this appendix are organized by the adaptation action areas identified by WUCA (Engage, Understand, Plan, Implement, Sustain) in its **Leading Practices report**. These resources supplement that report and provide a survey of the existing tools and information available—especially for people recently embarking on adaptation efforts or who have limited capacity—to support adaptation processes leading to and including implementation.

Engage

Motivation and support are essential for successfully initiating, implementing, and sustaining adaptation action.

Resilient Metrics - Job Aid: Identifying and Effectively Engaging Stake- and Rights-holders

Antioch University's Center for Climate Preparedness and Community Resilience - Strategies for 21st Century Risk Management and Climate Change Communication webinar

Yale Program on Climate Change Communication - Visualizations and Data Tools

WUCA - Training and Presentation Resources

Climate Central – Surging Seas Maps and Tools

NOAA Office of Coastal Management – Sea Level Rise Viewer

San Francisco Bay Conservation & Development Commission (BCDC) – Community Vulnerability Mapping and Community-Based Organization Directory Map

California Coastal Commission - California King Tides Project

I-Storm

Understand

Knowing you water system—how it currently functions, how it has faltered or failed under previous conditions, and how future conditions (e.g., sea level rise, flooding, extreme heat, wildfires, drought) may impact its ability to operate effectively—will help you identify and understand existing and potential future limitations as well as provide context to assess risk and opportunities for adaptation action.

NOAA's Tides and Currents Initiative - Extreme Water Levels Tool

NOAA – 2022 Sea Level Rise Technical Report

NOAA – Application Guide for the 2022 Sea Level Rise Technical Report

California Energy Commission, University of California, Berkeley, California Strategic Growth Council - Cal-Adapt

WUCA - Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change

City and County of San Francisco, CA - Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaptation

The Washington Coastal Resilience Project - How to Choose: A Primer for Selecting Sea Level Rise Projections for Washington State

Global Water Operators' Partnerships Alliance (GWOPA) - A Tool for Coastal and Small Island State Water Utilities to Assess and Manage Climate Change Risk

San Diego Association of Governments (SANDAG) - Regional Transportation Infrastructure Sea Level Rise Assessment and Adaptation Guidance

San Diego Association of Governments (SANDAG) - Adapting to Climate Change: A Planning Guide for State Coastal Managers

Azevedo de Almeida BA, Mostafavi A. 2016. - Resilience of Infrastructure Systems to Sea Level Rise in Coastal Areas: Impacts, Adaptation Measures, and Implementation Challenges. Sustainability 8(1115):1-28

Brown C, Ghile Y, Laverty M, Li K. 2012. - Decision Scaling: Linking Bottom-up Vulnerability Analysis with Climate Projections in the Water Sector. Water Resources Research 48(9)

Eakin H, Parajuli J, Yogya Y, Hernandez B, Manheim M. 2021. - Entry Points for Addressing Justice and Politics in Urban Flood Adaptation Decision Making. Current Opinion in Environmental Sustainability 51: 1-6

Lempert RJ, Groves DG. 2010. Identifying and Evaluating Robust Adaptive Policy Responses to Climate Change for Water Management Agencies in the American West. Technological Forecasting & Social Change 77(6):960-974 https://www.rand.org/pubs/external_publications/EP201000193.html

Sadler JM, Goodall, JL, Behl M, Bowes BD, Morsy MM. 2020. Exploring Real-Time Control of Stormwater Systems for Mitigating Flood Risk Due to Sea Level Rise. Journal of Hydrology 583: 124571

Miller IM, Morgan H, Mauger G, Newton T, Weldon R, Schmidt D, Welch M, Grossman E. 2018. Projected Sea Level Rise for Washington State: A 2018 Assessment. Prepared for the Washington Coastal Resilience Project. Updated July 2019.

U.S. Army Corps of Engineers – Sea Level Change Curve Calculator

Asefa T, Clayton J, Adams A, Anderson D. 2014. – Performance Evaluation of a Water Resources System Under Varying Climatic Conditions: Reliability, Resilience, Vulnerability and Beyond. Journal of Hydrology 208: 53-65

Adapting to Rising Tides – Maps and Data

EPA – Storm Water Management Model (SWMM)

Plan

Planning for adaptation includes identifying, evaluating, and prioritizing adaptation options. This action area provides for the explicit identification of consensus-based desired outcomes, management and planning targets, and adaptation options from which to prioritize. During the planning process, it is important to address uncertainties associated with climate science, how ecosystems and built systems will respond, and the social and governance structures in which adaptation measures need to be implemented. An adaptive management approach helps decision-makers consider a range of future conditions and prioritize options that spread risk across different adaptation options (e.g., protect versus retreat). Practitioners may decide to continue to pursue current management activities, make modifications to current strategies to better address sea level rise, and/or advance new and novel approaches to sea level rise.

Adaptation Pathways Generator

EPA - Adaptation Strategies Guide for Water Utilities

UN Environment - Climate Change Adaptation Technologies for Water: A Practitioner's Guide to Adaptation Technologies for Increased Water Sector Resilience

EPA - Flood Resilience: A Basic Guide for Water and Wastewater Utilities

Toronto and Region Conservation for the Living City and Credit Valley Conservation - Low Impact Development Stormwater Management Planning and Design

Bertule M, Appelquist LR, Spensley J, Trærup SLM, Naswa P. 2018 - Climate Change Adaptation Technologies for Water: A Practitioner's Guide to Adaptation Technologies for Increased Water Sector Resilience. UNEP DTU Partnership

Brodmerkel A, Carpenter AT, Morley KM. 2020 - Federal Financial Resources for Disaster Mitigation and Resilience in the U.S. Water Sector. Utilities Policy 63

de Graaf R, van de Giesen, van de Ven F. 2009.- Alternative Water Management Options to Reduce Vulnerability for Climate Change in the Netherlands. Natural Hazards 51(407)

Goodhew T. 2014. - Coastal Flood Defenses: Strategies for Protection in the United Kingdom. In Water Resources in the Built Environment: Management Issues and Solutions. Eds. Booth CA, Charlesworth SM

Center for Planning Excellent – Advancing Community Adaptation: A Framework for Project Prioritization and Decision Making

Erfani T, Pachos K, Harou JJ. 2018 – Real-Options Water Supply Planning: Multistage Scenario Trees for Adaptive and Flexible Capacity Expansion Under Probabilistic Climate Change Uncertainty. Water Resources Research 54(7):5069-5087

Sadr SMK, Casal-Campos A, Fu G, Farmani R, Ward S, Butler D. 2020. Strategic Planning for the Integrated Urban Wastewater System Using Adaptation Pathways. Water Research 182: 116013

EPA Climate Ready Estuaries – Synthesis of Adaptation Options for Coastal Areas

Indiana University Environmental Resilience Institute – Adaptation Strategies for Sea Level Rise

Coastal-Marine Ecosystem-Based Management Tools Network, NatureServe - Tools for Coastal Climate Adaptation Planning

Implement

Adaptation implementation includes changes made to an agency's activities, operations, and assets. These changes put priority adaptation options into action and can build resilience to sea level rise. Many adaptation initiatives encounter barriers in the transition from planning to implementation (WUCA, 2021).

Maryland Department of Planning - Maryland's Plan to Adapt to Saltwater Intrusion and Salinization

San Francisco Estuary Partnership - Transforming Shorelines: Advancing Nature-Based Solutions and Building Capacity for Innovative Approaches Linked to Wastewater Treatment

Molinaroli E, Guerzoni S, Suman D. 2019. - Do the Adaptations of Venice and Miami to Sea Level Rise Offer Lessons for Other Vulnerable Coastal Cities? Environmental Management 64:391-415

London Climate Change Partnership - Adaptation Pathways Started Kit

EcoAdapt and Foresight Partners Consulting – Climate Change Adaptation Certification Tool

Considine C, Covi M, (Wie) Yusuf JE. 2017. Mechanisms for Cross-Scaling, Flexibility and Social Learning in Building Resilience to Sea Level Rise: Case Study of Hampton Roads, Virginia. American Journal of Climate Change 6:385-402

Sustain

In order for climate adaptation efforts to be effective in the long term, there must be a pathway/plan to sustain these actions from the start. Monitoring and evaluation of implemented strategies, maintaining partnerships, and continually learning how you can integrate adaptive management approaches into your utility are essential to sustaining action. Mainstreaming climate adaptation into your organization's mission and operations help sustain the processes needed to adapt to climate change beyond the creation of an adaptation plan.

Brown S, Wadey MP, Nicholls RJ, Shareef A, Khaleel Z, Hinkel J, Lincke D, McCabe MV. 2019. - Land Raising as a Solution to Sea Level Rise: An Analysis of Coastal Flooding on an Artificial Island in the Maldives. Journal of Flood Risk Management 13:e12567

Cecchetti AR, Stiegler AN, Graham KE, Sedlak DL. 2020. - The Horizontal Levee: A Multi-Benefit Nature-Based Treatment System That Improves Water Quality and Protects Coastal Levees from the Effects of Sea Level Rise. Water Research X. 7: 100052

Davtalab R, Mirchi A, Harris RJ, Troilo MX, Madani K. 2020. - Sea Level Rise Effect on Groundwater Rise and Stormwater Retention Pond Reliability. Water. 12(4) 1129

Heal KV. 2014. - Constructed Wetlands for Wastewater Management. In Water Resources in the Built Environment: Management Issues and Solutions. Eds. Booth CA, Charlesworth SM.

Mensah KO, FitzGibbon J. 2013. - Responsiveness of Ada Sea Defense Project to Salt Water Intrusion Associated with Sea Level Rise. Journal of Coastal Conservation 17:75-84

B. Literature Review

Overview

The goals of this literature review were to identify any available evidence on:

- What factors have limited implementation of sea level rise adaptation and what (if anything) has been done to overcome specific barriers (e.g., funding, policy mechanisms) in the water resources sector
- If and how particular adaptation actions have been successfully implemented to address sea level rise in the water resources sector

We conducted a search of academic databases (e.g., Google Scholar, Web of Science) for scientific and gray literature (e.g., white papers, agency reports) published since 2000 on sea level rise adaptation. We identified hundreds of potentially relevant articles and papers and selected over 80 for more in-depth review based on their relevance to the implementation of sea level rise adaptation and adaptive management in water resources management. Thirty-one of these papers were used to develop this literature review. Literature sources not selected for review included those that did not directly address the implementation of adaptation measures as well as those that simulated the implementation of adaptation options (e.g., Bloetscher et al. 2011, Hall et al. 2019). It is important to note that this literature review highlights examples of barriers to adaptation in the water sector and, if applicable, the solution used to overcome that barrier. Overall, the literature on adaptation measures being implemented on the ground to address sea level rise by the water sector is extremely limited. Therefore, examples from the literature are supplemented with interview results, WUCA member questionnaires, and case studies of other projects that may be relevant to the water sector.

Barriers to Sea Level Rise Adaptation

Examples from the literature review and interviews are categorized by governance, financial, technical, and social/cultural barriers. **Governance** barriers include the presence and rigidity of regulatory and policy measures, scaling and land-ownership challenges, and a lack of clarity on who is responsible for on-the-ground implementation. **Financial** barriers include up-front and maintenance costs of adaptation measures, as well as the availability and flexibility of funding sources. **Technical** barriers are limits to the availability of adaptation options for implementation and if they can effectively reduce the effects of sea level rise based on factors such as available resources and capacity. **Social/cultural** barriers to adaptation may arise from conflicting interests of stakeholders and/or sectors (e.g., state versus local agencies, public versus private landowners).

Governance

Certain governance structures can challenge sea level rise adaptation. Using stakeholders in the San Francisco Bay as a case study, Lubell et al. (2021) identify several such challenges: lack of a central agency or institution with responsibility for sea level rise adaptation planning; difficulty developing a network governance model due in part to differing priorities, lack of a regional plan, difficulty obtaining the proper permits for gray or green infrastructure projects, lack of identified funding sources for projects, community attitudes and stakeholder priorities, and inconsistent support from political leaders and elected officials. Specific governance barriers highlighted in this section include those involving regulatory and policy measures, land ownership and responsibility, competing priorities, long-term planning and uncertainty, and flexibility in planning.

Regulatory and policy measures

- Restrictions in federal, state, and local land-use policies often limit the adoption and implementation of policies prohibiting development in areas vulnerable to SLR. In Florida, current laws also entitle private property owners to government compensation if the state tries to prohibit the use of seawalls and other protective measures along private coastal properties. Additionally, the high cost of right-of-way acquisition of coastal lands can limit the application of infrastructure relocation, particularly roads and underground utilities (Deyle et al. 2007).
- Maryland has adopted well construction mandates to limit the potential salinization of coastal water supplies: "Wells must be constructed at least 2 feet above grade in flood-prone areas (COMAR 26.04.04.21.C). Flood-resistant caps, which include a gasket that forms a waterproof seal, on wells must be used in flood-prone areas (COMAR 26.04.04.21.G)" (Maryland Department of Planning 2019, pg. 28).
- The City of Santa Barbara's local comprehensive plan explicitly disfavors the hard armoring of shorelines to protect private property: "Shoreline protection devices shall be prohibited unless they are necessary to, and will accomplish the intent of protecting public beaches, coastal-dependent uses, existing public structures, and existing principal structures (main living quarters, main commercial buildings, and functionally necessary appurtenances to those structures, such as wastewater and water systems, utilities, and other infrastructure) in danger from erosion" (City of Santa Barbara 2019, pg. 16-17).

Land ownership and responsibility

- Lawrence et al. (2020) focuses on governance issues related to pre-emptive managed retreat, including uncertainty over who is responsible for implementation, limited coordination between coastal sectors (e.g., infrastructure, public utilities), weak political leadership, and decision-making inertia. The paper recommends ways to enable effective implementation of managed retreat, including anticipatory planning, mainstreaming of adaptation into all strategic policy processes, establishing clarity on decision-making and responsibilities, and incorporating monitoring and evaluation requirements into every adaptation implementation plan.

Competing priorities

- Tampa Bay Water (TBW) serves three counties and three cities on the Gulf Coast of Florida. The utility's efforts to address sea level rise adaptation have been limited in the past as the agency focused on other climate change issues (primarily, the impacts of changes in precipitation and temperature on water supply and demand). TBW needs increased resources, funding, support from executive-level personnel, and local political recognition of the impacts of sea level rise in order to accelerate adaptation action. Currently, the TBW is developing a climate adaptation plan that will address these challenges. (TBW, personal communication, October 23, 2020).

Bhullar (2013) examines existing adaptation measures in Singapore's water sector and particularly within the city-state's reservoirs, which are at risk from sea level rise and saltwater intrusion. Existing strategies that have been implemented include the installation of hard embankments and revetments, widening and deepening of drains and canals, and expansion of public education. Success in water adaptation in Singapore is attributed to strong political will, effective legal and regulatory frameworks, and an engaged public.

Long Term Planning and Uncertainty

The use of long-term planning horizons may complicate the prioritization and implementation of adaptation measures due to uncertainty in sea level rise projections (Azevedo de Almeida & Mostafavi 2016). However, failing to consider likely changes over longer time scales can result in the prioritization of adaptation measures that will not ultimately address the full scale of sea level rise-related challenges, particularly when considering infrastructure with a longer lifespan (i.e., a facility expected to last for 50+ years). Donner & Webber (2014) note that a rolling planning horizon may reduce uncertainty by allowing for revisions to regulations as new projections and other scientific findings (e.g., tradeoffs between adaptation options) become available, while also ensuring that planning occurs at timescales appropriate to long-term needs: "One risk of a short-term planning horizon is a bias towards inexpensive measures which may be inadequate to combat the more existential decade-century scale threats from sea level rise. Without concurrent long-term planning, the more resource-intensive adaptation measures, like land reclamation and international migration, will be more challenging to implement" (Donner & Webber 2014, pg. 340).

Gibbs (2016) suggests that while there are a plethora of coastal adaptation plans and projects, few have been implemented due to inadequate considerations of political risks and differential impacts of adaptation measures during the planning process. Short-term thinking of elected officials and government agencies may lead to a "plan and forget" approach to coastal adaptation, wherein climate risks are considered and plans are created but implementation lags due to vague/over-simplified language or avoidance of public conflict causes implementation to lag. "...it appears plausible that if coastal [adaptation] studies implicitly assume that success is determined by the number of buildings that get partially or fully inundated in the future, but governing agencies view success in terms of either welfare [maximizing] or [minimizing] negative press, then a low level of uptake is likely to result, which coincidentally is what we are currently observing. This presents a conundrum in that the coastal adaptation strategies that [minimize] future risks to buildings may be precisely the approach that exposes decision makers to immediate personal and [organizational] risk" (Gibbs 2016, pg. 112).

Flexibility in planning

Lumbroso & Ramsbottom (2018) reviews the creation of the Thames Barrier and implementation of the Thames Estuary 2100 (TE2100) plan. They note that the flexibility incorporated into the plan is particularly important when dealing with infrastructure investments that have high costs, long construction times and expected lifetimes, and high risks associated with their failure. Options in the plan were developed based on triggers and thresholds (e.g., frequency of barrier closures). The timing of each intervention is based on "the rate of change of the indicator (which is unlikely to be linear); the threshold value when an intervention is required; an estimate of how the indicator will continue to change, in order to estimate the date when it reaches the threshold value; [and] the lead time for planning and constructing the intervention" (Lumbroso & Ramsbottom 2018, pg. 7) The indicators include the rate of sea level rise, peak river flows, erosion, the condition of intertidal habitat and flood defenses, operations of the Thames Barrier, shoreline development, and public attitudes to flood risk.

Financial

Financial barriers include upfront and maintenance costs of adaptation measures, as well as the availability and flexibility of funding sources.

- Unique financing mechanisms may be important to overcome financial barriers. For example, Ann Arbor, Michigan, provides credits on residents' stormwater utility bills for green infrastructure installation and maintenance of green infrastructure on private properties (e.g., rain barrels, gardens, porous pavers) as a way to reduce local stormwater pollution. The City determines stormwater rates based on the amount of pervious and impervious surface on the property. This funding structure incentivizes residents to decrease the amount of impervious surface on their property (i.e., property owners pay less when the area of impervious surface is small because less stormwater travels into the city's infrastructure). The City is using this approach to address expected increases in stormwater due to projected increases in precipitation and storm events in the region as a result of climate change (City of Ann Arbor 2021; Kershner 2012).
- Wedin (2021) conducted semi-structured interviews with local planners and policymakers representing municipalities, county administrative boards (from Skåne and Halland), and a local heritage site in southern Sweden. Several barriers were identified for sustainable and ethical sea level rise adaptation in the region, including a lack of frameworks for adaptation implementation financing. Interviewees provided suggestions for how to address this particular challenge, such as funding adaptation through taxes (local, municipal, national); charging those affected by sea level rise with fees; creating a redistributive tax policy; increasing insurance companies, which could increase premiums to discourage building in coastal zones; creating bank loan conditions that require higher security for houses in areas at risks of sea level rise; and increasing availability of centralized climate funds. The feasibility and equity of some of these suggestions were then discussed in greater depth, particularly in terms of necessary trade-offs or other challenges posed by the solutions themselves. For example, should a municipality be responsible for funding adaptation measures that protect people who are aware of the risks of sea level rise but continue to live and build in high-risk areas? If not, then who takes on this responsibility and how/where is this responsibility distributed? Should part-time residents who have homes in at-risk zones receive financial assistance even though they do not contribute to the municipal tax in the same way as permanent residents? There was some consensus among interviewees that a shared responsibility (across levels of governance) should exist when it came to financing adaptation to sea level rise. However, others felt that people who are aware of the risk and still choose to stay in place might not "deserve" the financial help for adaptation. Wedin asks "...should [it] be those who benefit from adaptation, those who have contributed to the problem, or those who have the ability or means who should be responsible for financing adaptation?" (Wedin 2021, pg. 512).
- Reguero et al. (2018) reviewed the cost-effectiveness of various coastal adaptation measures, including nature-based, structural, and policy measures with a focus on the U.S. Gulf Coast. Nature-based approaches were found to be more cost-effective in terms of implementation and maintenance over the long term.
- Rachelson (2019) developed a summary of key adaptation tools for municipalities to address sea level rise including external grants, capital budgets, and developer-driven finance. They highlight the case study of the City of Richmond, British Columbia to demonstrate the importance of diversifying funding mechanisms to support adaptation actions for flood protection and management. The City has received over $13.7 million in funding from governmental and regulatory bodies including the Disaster Mitigation and Adaptation Fund (dedicated to structural and natural infrastructure investments to increase resilience of communities to the impacts of climate change). The City of Richmond is using the funds to raise the city's dike network and upgrade 5 pump stations to reduce flooding. They are also diverting a local river to nearby farms for irrigation. In addition to the funds mentioned above, the City is supporting flood management efforts through a combination of internal and developer as part of a waterfront development initiative. Overall, the City of Richmond will spend over $50 million on flood protection and management by 2024.
- Bertule et al. (2018) reviews over 100 adaptation options for response to climate-driven changes in water supply and quality as well as sea level rise and disaster preparedness. Over 20 of these actions are related to sea level rise, with the primary focus being to limit saltwater intrusion, protect shorelines using built and natural infrastructure, and manage shoreline activities via accommodation techniques. Technologies associated with notable upfront costs include physical/hydraulic barriers to saltwater intrusion, sustainable aquifer recharge (e.g., injection wells, recharge basins, check dams), revetments, seawalls, beach nourishment, storm surge barriers/closure dams, breakwaters, groins, and jetties. Technologies that also require higher maintenance costs include saltwater intrusion physical/hydraulic barriers, beach nourishment, and storm surge barriers/closure dams. Lower maintenance costs are typically associated with natural infrastructure approaches (e.g., restoration of coral reefs, oyster reefs, and coastal wetlands). The table below summarizes the findings in Bertule et al. (2018) related to sea level rise adaptation actions.

Table 1. Bertule et al. 2018 Findings Related to Sea Level Rise Adaptation Actions

Approach	Action	Benefits (+) and Limitations (–)	Costs		Implementation Timeframe (i.e., amount of time needed to establish and/or reach full capacity)
			Upfront (i.e., investment needed to implement)	*Maintenance (i.e., operational costs)*	
Limit saltwater intrusion	Limit extraction from shallow aquifers	+ Reduces pressure on groundwater resources, promotes sustainable water use – High level of capacity required for monitoring and enforcement	Moderate to high	Moderate to high	Moderate to significant
	Create physical/hydraulic barriers to fluvial saltwater intrusion	+ Maintains freshwater coastal aquifer, improves access to freshwater for multiple uses – Expensive to establish, high operational costs	High	High	Moderate to significant
	Increase sustainable aquifer recharge (e.g., injection wells, recharge basins, check dams)	+ Reduces risk of saltwater intrusion, increases amount of fresh water available – Potential for water pollution and high evaporation	Moderate to high	Low to moderate	Low to moderate
	Coastal groundwater level monitoring	+ Supports decision-making on reducing impacts of saltwater intrusion – High costs for monitoring system and operation, lack of capacity	Moderate to high	Low to moderate	Moderate
	Coastal surface water monitoring	+ Supports decision-making on reducing impacts of saltwater intrusion – High costs for monitoring system and operation, lack of capacity	Moderate to high	Low to moderate	Moderate
Built infrastructure shoreline protection	Revetments	+ Limited interference with longshore sediment dynamics, may contribute to beach nourishment, typically long-lived structures, relatively simple to construct, relatively low maintenance required – Does not address sediment loss, may cause accelerated erosion of adjacent coastlines, construction may be complicated by high construction costs and low material availability	Moderate to high	Low to moderate	Low to moderate
	Sea walls	+ High protection from coastal erosion and flooding, requires less space than other defenses (e.g., dikes), can be raised in response to sea level rise, good longevity with proper maintenance – Subjected to significant wave impact, vertical seawalls may be more susceptible to undercutting, does not address sediment loss and may cause erosion downdrift	Moderate to high	Moderate	Moderate
	Land claim (e.g., gain land in areas previously below high tide)	+ Provides additional land for multiple uses, can use dredged materials – Must be done in conjunction with hard protections such as seawalls and dikes, may displace large volumes of water and alter natural processes	Moderate to high	Moderate to high	Moderate to significant
	Beach nourishment	+ Maintains natural coastal dynamics, highly flexible strategy, maintains aesthetic and recreational values, cost-efficient if sediment-borrowing sites are near nourishment site – Requires suitable unpolluted sediment as well as highly specialized equipment and expertise, need for continuous replenishment	Moderate to high	Moderate to high	Moderate
	Storm surge barriers/closure dams	+ Flexibly maintains majority of natural tidal dynamics while providing flood protection – High capital and maintenance costs, may cause flooding on barrier's landward side, can alter water chemistry by affecting inflows and outflows of water	Moderate to high	Moderate to high	Moderate to significant
	Breakwaters	+ Maintains coastline stability, protects shoreline from wave action, requires limited monitoring and maintenance – May disrupt longshore sediment transport and cause erosion, construction can be costly	High	Low to moderate	Low to moderate
	Dikes	+ Prevents inundation of low-lying coastal areas, limits salinization, tried-and-tested method – Requires high volumes of building materials and may be costly, large environmental footprint, permanently fixes coastline position	Moderate	Moderate	Moderate
	Groins	+ Widens beach, traps sediment, reduces erosion and dissipates wave energy – May be aesthetically unappealing	Moderate to high	Low to moderate	Low to moderate
	Jetties	+ Ensures water flow, stabilizes tidal inlets and river mouths – May trap sediment and cause coastal erosion on downdrift	High	Moderate to high	Moderate

Approach	Action	Benefits (+) and Limitations (–)	Costs		Implementation Timeframe *(i.e., amount of time needed to establish and/or reach full capacity)*
			Upfront (i.e., investment needed to implement)	*Maintenance (i.e., operational costs)*	
Natural infrastructure shoreline protection	Artificial reefs	+ Supports biodiversity, decreases wave velocity and impacts – Not always successful	Moderate to high	Low to moderate	Moderate
	Restoration and protection of coral and oyster reefs	+ Supports biodiversity, decreases wave velocity and impacts, improves water quality, reduces maintenance costs of built infrastructure – May be technologically and politically complex, not always successful	Moderate to high	Low to moderate	Moderate
	Cliff stabilization	+ Prevents erosion, retains cliff appearance for recreation and aesthetic values, low-tech required – Important source of coastal sediment in some areas so natural features need to be maintained, artificial smoothing or re-grading can negatively affect habitat	Low to moderate	Low to moderate	Low to moderate
	Seagrass beds	+ Decreases wave velocity, reduces wave impacts, supports fisheries – Competes with other shoreline property interests	Moderate to high	Low to moderate	Moderate
	Coastal wetlands	+ Provides storm and flooding protection, habitat, recreation, and aesthetic values – Competes with other interests in shoreline property	Moderate to high	Low to moderate	Low to moderate
	Dune construction and rehabilitation	+ Creates/maintains habitats, provides protection against flooding and erosion, preserves recreation opportunities, generally less expensive than engineered solutions – Competes for valuable coastal land, sometimes viewed as barrier to public access	Low to moderate	Low to moderate	Low to moderate
Accommodation and management	Coastal zoning	+ Allows for range of shoreline activities – Requires high degree of coordination, management, and enforcement	Low to moderate	Low to moderate	Significant
	Floodproofing	+ Minimizes need for hard protection measures, maintains coastal dynamics, avoids need to elevate or relocate structures, more affordable than seawalls and dikes, allows development in the flood zone – Requires collaboration and communication with residents and landowners, floodproofing measures not effective with high velocity floods and waves	Low to moderate	Low	Low to moderate
	Managed coastal realignment	+ Allows space for habitats, increases natural flood buffering capacity – May require forced relocation of infrastructure and can cause political and social controversy	Low to high	Low to moderate	Moderate to significant
	Coastal setbacks	+ Maintains natural shoreline dynamics; shoreline access; and low-cost alternative to seawalls or dikes – Needs to be continually reviewed to keep pace with sea level rise, may require landowner compensation	Moderate to high	Low to moderate	Low to moderate
	Fluvial sediment management	+ Maintains coastal elevation, thus minimizing erosion, land subsidence, and flooding – Requires balancing upstream and downstream interests (e.g., hydropower, agricultural irrigation, fluvial and coastal flooding)	Moderate to high	Moderate to high	Significant

Technical

Technical barriers are limits to the availability of adaptation options for implementation (i.e., what can be done, what resources are available) and/or to their effectiveness at reducing the impacts of sea level rise. Technical barriers can also include lack of staff capacity and technical ability; limited information and/or access to data; and lack of adaptation and risk management experience and expertise. Specific technical barriers highlighted in this section include those involving protective measures (e.g., wetlands and seawalls), strategies to accommodate flooding, and resource availability.

Protective measures (e.g., wetlands, seawalls)

- Venice, Italy, has engaged in several flood adaptation measures to address the compounding effects of land subsidence and flooding, ranging from seawall restoration and elevation of city infrastructure to beach nourishment and wetland construction (Molinaroli et al. 2019). One of its major initiatives has been the construction of MOSE (Modulo Sperimentale Elettromeccanico or Experimental Electromechanical Model; see: https://www.mosevenezia.eu/project/?lang=en), a network of mobile gates intended to isolate the Venice Lagoon from the Adriatic Sea during periods of high tides and combat anticipated sea level rise. MOSE has been designed to withstand floods of up to 10 feet but has been plagued by concerns over its high costs (~US$6.6 billion) as well as potential impacts on the lagoon ecosystem, water quality, and interruption of maritime traffic (Molinaroli et al. 2019; Hilburg 2020). On October 3, 2020, the system was used to combat a high tide event and successfully kept the city dry from over 2.3ft of flooding (Silvestri 2020). The MOSE was raised 33 times between 2020 and 2021, thus proving its utility in protecting the city against high tides and, potentially, future sea level rise. The MOSE consists of a total of 78 gates. While the flood gates were activated multiple times from 2019–2021 as engineers tested the system, the MOSE will be fully operational in 2023 (Buckley 2022, Voiland 2021).
- Mensah & FitzGibbon (2013) reviewed the effectiveness of the Ada Sea Defense Project near Ada, Ghana, which uses a combination of structural approaches (e.g., seawall, groins) and beach nourishment to address coastal erosion and saltwater intrusion. The study showed positive effects to date by reducing property loss and improving livelihood and economic opportunities, but minimal effects on groundwater salinization and a potential increase, and upstream shift of salinity was observed in the Volta River. Concern remains over how the defense project will fare under future conditions, as sea level rise was not integrated into the project design.
- Brown et al. (2019) evaluated sea level rise exposure and adaptation options to extend the lifetime of an artificial island (Hulhumalé) created in the 1990s, which had previously been raised to 1.8 meter above mean sea level to accommodate sea level rise and expansion of the Maldives population. To date, the artificial island has been able to keep pace with rising sea levels, but concerns over the rate and magnitude of sea level rise prompted an evaluation of additional options. The authors note that with no action, catastrophic flooding is likely to occur with an approximate 2 foot sea level rise. The most feasible options for island residents are strategic beach nourishment and seawalls. The findings show that different combinations of these approaches could be used to effectively reduce the island's vulnerability to catastrophic flooding: a 1.6-foot-high seawall could delay flooding from 0.6 foot of sea level rise; a 1.6-foot-high high seawall plus 60,000 cubic meters of beach nourishment could delay flooding from 1.3-foot sea level rise; a 3.2-foot-high seawall could delay flooding from 1.3 feet of sea level rise; and a 4.9-foot-high seawall could delay flooding from 1.9 feet of sea level rise.
- Heal (2014) evaluated the use of constructed wetlands for the management of wastewater (e.g., domestic and municipal wastewaters, contaminated stormwater runoff) in built and urban environments globally. They found that these wetlands provide multiple benefits, including reduced flood risk, and have been shown to remove more than 50 percent of contaminants to improve water quality.
- Hinkel et al. (2018) found that the primary challenge to sea level rise adaptation in New York City is fitting adaptation measures (e.g., the Lower Manhattan coastal protection and other large-scale storm surge barriers, large-scale storm surge barriers, green infrastructure-based protection) into existing high-density urban spaces.

Accommodate some flooding (e.g., retrofit, saltwater intrusion barriers, floodable development, desalination, green infrastructure, injection wells, design flood elevation)

- Hovik et al. (2011) reviewed adaptation in the water sector across five municipalities in Norway—Oslo, Bærum, Skedsmo, Rælingen, and Drammen—that own and operate water and wastewater infrastructure. Out-of-date and degraded infrastructure are major challenges to the water sector's adaptive capacity, and municipal personnel recommend that retrofitting or replacement should be accompanied by green infrastructure to slow flows.
- Werner (2010) reviewed operational controls (e.g., pumping and well-construction restrictions, water trading) and engineered artificial recharge schemes/recycled water (e.g., artificial recharge schemes, recycled water) approaches to saltwater intrusion in Australia. Groundwater trading (e.g., "selling the right to pump water from a shared aquifer"; Wheeler et al. 2016, pg. 499) has been successfully implemented in Pioneer Valley to reduce groundwater extraction from areas vulnerable to saltwater intrusion. Artificial recharge has been applied for decades in the Lower Burdekin (Queensland), Pioneer Valley, and Bribie Island aquifers, but there is limited evidence that artificial recharge has been successful in reducing intrusion impacts.
- In the City of Newport News, Virginia, the Waterworks utility rebuilt the Walkers Dam, a saltwater intrusion barrier on the Chickahominy River. To accommodate potential increased flooding from sea level rise and storm surge, the dam includes temporary barriers that can be raised to increase dam height and prevent saltwater intrusion into the upstream intake site. Other dams managed by Waterworks have been retrofitted to better withstand 100-year storm events (Reynier & Gregg 2021).

Resources available to implement

- Cao et al. (2020) evaluated the combined impacts of land subsidence and flooding from a 2011 earthquake and tsunami on three major wastewater treatment plants in Tōhoku, Japan, that experienced damage during the events, and then used this as a proxy for future sea level rise impacts on those plants. The authors identified several specific technical design elements that could be improved to limit wastewater treatment operational vulnerability under even moderate sea level rise projections. At ground level, infrastructure such as the pump station should be equipped with flood prevention measures and/or elevated to higher levels (e.g., relocated above the floodable ground level of the building). At the discharge level, discharge pumps or gates could help prevent saltwater intrusion. Groundwater pumping may also eliminate unknown inflows into treatment plants as groundwater levels rise with sea level.

Social/Cultural

Social or cultural barriers to adaptation may arise from conflicting interests of stakeholders and/or sectors (e.g., state versus local agencies, public versus private landowners, public resistance, negative effects on vulnerable groups).

- Harris-Lovett et al. (2018) reviews the social and institutional impediments to retrofitting existing or developing new resilient wastewater infrastructure in the San Francisco Bay Area in order to ensure it is capable of contending with nutrient and contaminant pollution in light of sea level rise and rapid population growth. Both social factors (e.g., public opinion and compliance) and institutional factors (e.g., lack of clear leadership, permitting issues, and collaboration between agencies and organizations with different mandates in the Bay Area) were identified by local stakeholders as the biggest limitations. To overcome these limitations, stakeholders recommended improving or maintaining existing communication and collaboration between water managers, regulators, and ecological stewards (e.g., Regional Monitoring Program for Water Quality in the San Francisco Bay, Bay Area Clean Water Agencies), and making the multiple benefits of wastewater treatment (e.g., resilience to sea level rise, increasing wetland habitats) more visible to encourage public support and compliance.
- Community input and engagement early on in the adaptation planning process is critical to match adaptation actions to specific community needs (Azevedo de Almeida & Mostafavi 2016).
- The Pierce County Planning and Public Works Department Sewer Division has developed a series of strategies to make wastewater infrastructure more resilient to sea level rise and flooding, in both near-term and long-term timeframes. Near-term strategies include incorporating climate change into long-range planning and continuing to monitor inflow and infiltration within the collection system. Long-term strategies include expanding onsite use of reclaimed water at Chambers Creek Regional Wastewater Treatment Plant and exploring options for increased groundwater infiltration more broadly in County's sewer service (C. Moore and D. Dixon, personal communication, August 24, 2020). Some Public Works Department staff are dedicated to the issue of adaptation, and they foresee flooding and sea level rise impacting the department's ability to provide high-quality and low-cost services. However, there is no federal or state mandate for adaptation, and there is a lack of interest from local elected officials, politicians, and stakeholders. The County is working to incorporate sea level rise projections into community outreach initiatives and hopes to gain local support for the topic. The Sewer Division is combining efforts to address sea level rise with existing priorities, but funding is scarce and the lack of a sense of urgency around sea level rise limits action.
- In the Solomon Islands and other Pacific island countries, higher frequency precipitation, flooding, and damage to water infrastructure is intensifying existing challenges surrounding water security. There is often a lack of technical and financial resources to restore damages, install and operate systems (e.g., desalination and ultrafiltration units), or maintain existing infrastructure, but social factors and effective community involvement also remain large challenges for this region when it comes to climate change adaptation implementation. Locally, climate adaptation programs are seen as products of funding agencies who provide the funding and thus are under the influence of their agendas instead of working in concert with local communities and governments to discover ways to incorporate local context into long-term sustainability. Dorevella et al. (2021) conclude that climate change adaptation programs are often fixated on specified outcomes and goals, which can limit the amount of time spent on the "exploration of power relations, cultural worldviews, and experiences" that could result in more successful implementation (Dorevella et al. 2021, pg. 12).

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C. Adaptation Pathways and Application in Water Resources

To identify and summarize similarities and differences in adaptive management principles (e.g., robust decision-making and dynamic adaptation policy pathways), a text search in Web of Science was conducted to identify papers to define each term and explain its applications. Then, case studies using each principle were identified through a text query of the Climate Action and Resilience Plan Database provided by **Consortium for Climate Risk in the Urban Northeast**, which contains over 270 local plans from across the United States. The database was queried using NVivo text analysis software. In instances where case studies could not be found, the literature review was extended to include international examples.

There is a wide variety of adaptive management approaches, many of which build off of each other. It is therefore useful to consider the compatibilities between many of these approaches, rather than viewing them as mutually exclusive options. Within the literature, there are unique distinctions between each approach that make them more or less appropriate under different circumstances; in practice, many communities and utilities have combined features of multiple approaches to best suit their context-specific priorities and climate risks. Additionally, many communities use comparable or compatible adaptation approaches without necessarily specifying the terms included in the table below. The approaches included herein are predominantly used within academic, technical, or planning documents and do not capture the breadth of local and traditional ecological knowledges used as the basis for adaptive management.

The table is color-coded and ordered to highlight connections and similarities between approaches. For example, the backcasting approach is a type of scenario planning; robust decision-making is complementary to dynamic adaptive policy pathways; and real options analysis aligns with adaptive management. While the colors capture overarching similarities, the relationships between these strategies are complex; trade-offs and co-benefits should be thoughtfully considered when determining which approach(es) to employ in adaptation planning.

Strategy	Definition	Features	Case studies
Scenario planning	"The purpose of scenario planning is to allow practitioners to conceptualize stories about alternative futures to improve institutional decision-making and manage for risk and uncertainty" (Cobb and Thompson 2012)	• Exploratory scenarios trace plausible futures but do not make predicts or outline how to achieve a particular desirable future • Compatible with participatory methods	**Tucson Water, Arizona:** a conceptual planning timeline, which extends from 2000 to 2050 (HDR Engineering, Inc. 2013) **Marin County, California:** Sea level rise and storm scenarios for planning (SPUR 2012)
Backcasting approach	"1) the development of desirable images of the future (visions) and 2) a backwards analysis of how these visions can be realized" (van Vleit & Kok 2013)	• A type of normative scenario approach aiming to achieve a particular future • Can include qualitative or quantitative data • Can be combined with exploratory scenarios to increase robustness	**SCENES:** Water scenarios for Europe and neighboring states **Greater New Orleans Urban Water Plan:** provides normative visions of 'urban water corridors'
Robust decision-making (RDM)	"Rather than using computer models and data as predictive tools, the approach runs models myriad times to stress test proposed decisions against a wide range of plausible futures. Analysts then use visualization and statistical analysis of the resulting large database of model runs to help decisionmakers identify the key features that distinguish those futures in which their plans meet and miss their goals" (Lempert 2019)	• Complementary with Dynamic Adaptive Policy Pathways • Combines decision analysis, assumption-based planning, scenarios, and exploratory modeling • Provides decision support under deep uncertainty • Utilizes the concept of "plausible futures" from scenario analysis • Seeks robust strategies (which perform well over a wide range of future scenarios) rather than optimal strategies	**Colorado:** Uses RDM to support long-term water resources planning for the Colorado River Basin (Groves et al. 2019) **Southern California's Inland Empire Utilities Agency:** Used RDM to evaluate impacts of climate change on long-term urban water management (Lempert & Groves 2010)
Adaptation pathways	"...an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time" (Haasnoot et al. 2013)	• Provides a pathway map useful in visualizing options over time • Includes adaptation tipping points and presents possible options after a tipping point has been reached using adaptation trees • Provides information on path dependencies • Presents multiple routes to achieve the same desired outcome • Quantitative targets are necessary to determine the success of a pathway or action	**Miami, Florida:** estimated economic feasibility of multiple adaptation pathways **Lakes Entrance, Australia:** tested the use of adaptation pathways to address sea level rise and conflicts regarding coastal development between city officials and residents. The process indicated that identifying triggers and tipping points that are socially salient to residents is critical to success because it highlights unacceptable impacts for people, provides participants with a sense of ownership over scenarios, and builds consensus for action (Barnett et al. 2014)

Strategy	Definition	Features	Case studies
Adaptive policymaking	"...a stepwise approach for developing a basic plan, and contingency planning to adapt the basic plan to new information over time" (Haasnoot et al. 2013)	• Complementary to adaptive pathways • Includes trigger points and signposts to determine if the plan is meeting goals • A plan to realize a decision-maker's normative vision • Provides a broad framework rather than clear guidance	**Netherlands:** developed a national civil aviation policy
Dynamic adaptive policy pathways (DAPP)	"This integrated approach includes: transient scenarios representing a variety of relevant uncertainties and their development over time; different types of actions to handle vulnerabilities and opportunities; Adaptation Pathways describing sequences of promising actions; and a monitoring system with related contingency actions to keep the plan on the track of a preferred pathway" (Haasnoot et al. 2013)	• A combination of adaptive policymaking (contingency planning, triggers, and monitoring) and adaptation pathways (pathway maps)|• Focuses on keeping options open and including adaptation over time • Strength: more comprehensive than either strategy individually • Weakness: more complex than either strategy individually	**Netherlands:** developed pathways for water management of the Rhine Delta (Haasnoot et al. 2013) **Wellington, New Zealand:** Sea level rise thresholds evaluated using DAPP and test strategy for managed retreat of water infrastructure developed to identify options to maintain services under varying sea level rise rates (Kool et al. 2020)
Flexible adaptation pathways	"Flexible adaptation pathway(s) is a relatively loose term used to look at how building flexibility in to adaptation can help to manage the long-term and uncertain nature of climate change impacts" (Moss & Martin 2012)	• General term for a suite of approaches rather than a specific methodology • Uses risk-based decision frameworks, thresholds, and/or trigger points • Interchangeable with 'decision pathways'	**Hampton Roads, Virginia:** using the framework to determine low-cost, no-regret actions in the present, while investigating strategies to implement in the future (Hampton Roads Planning District Commission 2013) **ConEdison, New York City:** tracking conditions affecting system resilience with pre-defined thresholds (ConEdison 2019) **New York City Panel on Climate Change:** advancing tools and methods for flexible adaptation pathways (Rosenzweig & Solecki 2019)
Trigger points	"A trigger specifies the conditions under which a pre-specified action to change the plan is to be taken" (Haasnoot et al. 2013)	• Part of adaptive policymaking approach • Strength: clarifies timeframes for action	**Marin County, California:** determining trigger points for compromised septic leach fields (Marin County Community Development Agency 2018) **Sacramento, California:** using trigger points to determine water-efficiency upgrade installation (City of Sacramento 2012) **Southwest Australia:** trigger points for decisions established along the protect-accommodate-retreat coastal adaptation spectrum (Grace & Thompson 2020)
Adaptation tipping point(s)	"...the point at which a particular action is no longer adequate for meeting the plan's objectives" (Haasnoot et al. 2013)	• Part of adaptation pathways approach • Weakness: difficult to detect with lead time • Also referred to as thresholds	**Mertarvik, Alaska:** population thresholds for relocation efforts to trigger school, airport, and post office services (Newtok Planning Group 2011) **Laguna Woods, California:** thresholds set to determine no-regret, more aggressive, and very aggressive strategies (City of Laguna Woods 2014) **Metlakatla Indian Community, Alaska:** thresholds set for water levels in the municipal supply to trigger water conservation practices (Scott et al. 2017) **New Zealand:** Adaptation tipping points may include failed performance of an action or changes in community coping capacity (Stephens et al. 2018) **Netherlands:** Applies tipping points to water management efforts to defend against floods, protect drinking water, and protect Rotterdam Harbor (Kwadijk et al. 2010)
Adaptive management	"Adaptive management [is a decision process that] promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process" (Williams et al. 2009)	• Facilitates social and institutional learning • Compatible with participatory processes • Can be resource-intensive	**Ocean Beach, California:** includes ongoing monitoring of conditions as they develop over time (SPUR 2012) **Broward County, Florida:** setting short-, intermediate-, and long-range goals and establish adaptive management implementation strategies for water resources (Broward County 2015) **Thurston County, Washington:** iteratively updating the plan with new climate information and community input (Thurston Regional Planning Council 2018) **Clarence, Australia:** The Clarence City Council included evidence-based monitoring and evaluation as a requirement for adaptation measures to allow for necessary revisions and updates based on real-world changes in environmental and socioeconomic conditions (Abunassr et al. 2013)

Strategy	Definition	Features	Case studies
Adaptive co-management	"Adaptive co-management is an emergent governance approach for complex social–ecological systems that links the learning function of adaptive management (experimental and experiential) and the linking (vertically and horizontally) function of co-management" (Plummer et al. 2012)	• Combination of adaptive management and co-management • Strength: emphasizes collaboration, pluralism, and communication • Challenge: more resource-intensive and complex than either strategy individually	**England:** enabling freshwater ecosystem protection and livelihood sustainability through uncertain water futures (Whaley & Weatherhead 2016)
Real options analysis	"Real Options Analysis quantifies the investment risk associated with uncertain future outcomes. It is particularly useful when considering the value of flexibility of investments. This includes the flexibility over the timing of the capital investment, but also the flexibility to adjust the investment as it progresses over time" (Watkiss et al. 2013)	• Used to determine whether to invest now or at a later point in time • Aligns with adaptive management • Utilizes decision trees for visualization • Strength: informs large investment decisions through economic analysis of the value of flexibility and information • Weakness: complexity requires expert knowledge and resources • Few examples of application to adaptation	**London, England:** Multi-stage scenario trees for water supply planning for water utilities (Erfani et al. 2018)
Decision scaling	"The use of a decision analytic framework to reveal the scaling of climate information that is needed to best inform the decision at hand. In decision scaling, the premise is that discussion of appropriate downscaling methods should follow and be informed by the formal modeling of the decision of interest" (Brown et al. 2012)	• Links vulnerability assessment with climate projections • Utilizes a wide variety of climate information sources for decision-making • Uses stochastic analysis • Stakeholder-centered, risk-based framework	**BUA Knowledge Platform:** eco-engineering decision-scaling for water management

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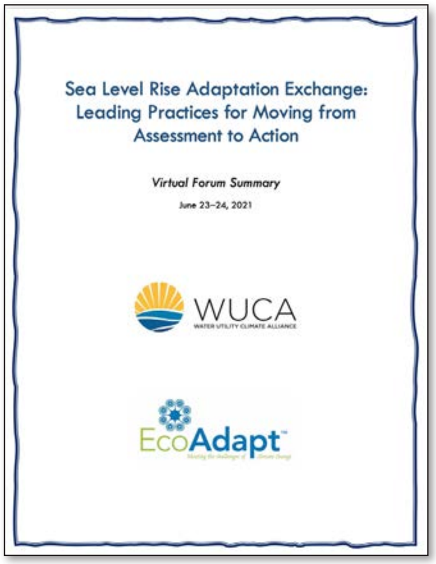

D. Sea Level Rise Adaptation Exchange (Virtual Forum) Summary

The virtual forum ***Sea Level Rise Adaptation Exchange: Leading Practices for Moving from Assessment to Action*** was held on June 23-24, 2021 and included presentations and breakout discussion groups. The goal of the forum was to document leading practices in sea level rise adaptation from the water sector. Stakeholders from coastal cities in the U.S. came together to discuss sea level rise adaptation opportunities and barriers, including unique challenges faced by water utilities and other infrastructure managers.

The full forum summary can be found here.

Presentations and Speakers

WUCA member highlights of efforts to date on sea level rise adaptation and overviews of barriers to and opportunities for advancing adaptation.

Seattle:

Ann Grodnik-Nagle (Strategic Advisor, Climate Adaptation and Built Environment, Seattle Public Utilities) and **Miles Mayhew** (Strategic Advisor, Seattle Public Utilities)

Philadelphia:

Julia Rockwell (Climate Change Adaptation Program Manager, Philadelphia Water Department) and **Abby Sullivan** (Environmental Scientist Specialist, Philadelphia Water Department)

New York City:

Alan Cohn (Managing Director, Integrated Water Management, New York City Department of Environmental Protection) and **Erika Jozwiak** (Infrastructure Program Manager, New York City Mayor's Office of Resiliency)

Tampa Bay:

Kay Parajuli (Water Resources Systems Engineer, Tampa Bay Water) and **Tirusew Asefa** (Planning and Systems Decision Support Manager, Tampa Bay Water)

Case studies from other cities that have implemented sea level rise adaptation measures to share lessons learned, including highlighting how specific factors have hindered or facilitated action.

Miami-Dade, FL:

Katherine Hagemann (Adaptation Program Manager, Miami- Dade County), **Annalise Mannix** (Planning and Development Division Chief, Miami-Dade Water and Sewer Department), and **Enrique Vadiveloo** (Senior Associate, Hazen and Sawyer, consultant to Miami-Dade Water and Sewer Department)

Virginia Beach, VA:

CJ Bodnar (Stormwater Technical Services Program Manager, City of Virginia Beach)

Boston, MA:

Charlie Jewell (Director of Planning, Boston Water and Sewer Commission) and **John Sullivan** (Chief Engineer, Boston Water and Sewer Commission)

San Francisco, CA:

David Behar (Climate Program Director, San Francisco Public Utilities Commission), **Adam Varat** (Acting Director, San Francisco Planning Department), **Anna Roche** (Project Manager, San Francisco Public Utilities Commission), **Luiz Barata** (Senior Architect and Urban Designer, San Francisco Planning Department), and **Brad Benson** (Port of San Francisco)

Attendees

Name	Affiliation
Abby Sullivan	Philadelphia Water Department
Adam Varat	San Francisco Planning Department
Adrienne Hampton	Duwamish River Community Coalition
Akshay Iyengar	Seattle City Budget Office
Alan Cohn	NYC Department of Environmental Protection
Alan Olmsted	NYC Department of Transportation
Alberto J. Rodríguez	Seattle City Office of Sustainability and Environment
Allan Biddlecomb	Pasco County, FL
Allison Lau	Philadelphia Water Department
Anjuli Corcovelos	San Diego County Water Authority
Ann Grodnik-Nagle	Seattle Public Utilities
Anna M. Roche	San Francisco Public Utilities Commission
Annalise Mannix	Miami-Dade Water and Sewer
Brad Benson	Port of San Francisco
Brejesh Prayman	St. Petersburg Public Works
Carolyn Caton	Philadelphia Office of Emergency Management
Cathleen Jonas	HSW Engineering
Charles Olson	NYC Water and Sewer Operations
Charlie Jewell	Boston Water and Sewer Commission
CJ Bodnar	City of Virginia Beach
Claude Tankersley	St. Petersburg Public Works
Clay Clifton	Sweetwater Authority
Cynthia McCoy	City of Seattle
Daley Dunham	Port of San Francisco
David Behar	San Francisco Public Utilities Commission
David Goldberg	Seattle Office of Planning and Community Dev.
Diana Smillova	St. Petersburg, Fl
Elena Fisher	Philadelphia Airport Division of Aviation
Elizabeth Lankenau	City of Philadelphia
Enrique Vadiveloo	Hazen and Sawyer
Erika Jozwiak	NYC Mayors Office
Goldy Herbon	San Diego County Water Authority
Greg Mayes	NYC Department of Environmental Protection
Jeff Harris	Pasco County, FL
Jessi Kershner	EcoAdapt
Joel Brown	Pinellas County, Fl
Joel Lehn	Seattle Department of Construction & Inspections
John Haak	Philadelphia Planning Commission
John Palenchar	St. Petersburg, Fl
John Sullivan	Boston Water and Sewer Commission
Josh Lippert	City of Philadelphia
Julia Rockwell	Philadelphia Water Department
Kathryn Braddock	EcoAdapt
Katherine Hagemman	Miami-Dade County
Kelly Anderson	Philadelphia Water Department
Kshitij (Kay) Parajuli	Tampa Bay Water
Laura Hilberg	EcoAdapt
Luiz Barata	San Francisco Planning Department
Maggie Glowacki	Seattle Department of Construction & Inspections
Marc Cammarata	Philadelphia Water Department
Melanie Garrow	Philadelphia Water Department
Michael Marrella	NYC City Planning Department
Miles Mayhew	Seattle Public Utilities
Miranda Cashman	NYC Department of Environmental Protection
Pat Perhosky	Philadelphia Water Department
Rachel Gregg	EcoAdapt
Radcliffe Dacanay	Seattle Department of Transportation
Rania Amen	Santa Fe Irrigation District
Saleem Chapman	Philadelphia Sustainability Office
Sarah Minick Commission	San Francisco Public Utilities
Shefalee Patel	NYC Department of Design & Construction
Sofia Zuberbuhler-Yafar	NYC Department of Design & Construction
Steve Carrea	NYC Department of Environmental Protection
Tirusew Asefa	Tampa Bay Water
Todd Burley	Seattle Parks and Recreation

E. Interviews and Questionnaires

This guide includes information and case studies derived from over 16 semi-structured interviews conducted with water utility staff and resilience leaders from around the United States. Questionnaires were also provided to several WUCA member agencies (Philadelphia Water Department, Portland Water Bureau, Seattle Public Utilities, and Tampa Bay Water). Below is a list of interviewees, individuals, and agencies consulted during the development of this guide.

Interviews

Alan Cohn
New York City Department of Environmental Protection

Nate Kimball
New York City Mayor's Office of Resiliency

Toni Utterback
City of Virginia Beach Public Works

Doug Yoder & Debbie Griner
Miami-Dade County Water & Sewer Department

Paula Shea
City of Norfolk

John Sullivan & Charlie Jewell
Boston Water and Sewer Commission

Cassandra Moore & Dennis Dixon
Pierce County Public Works and Utilities

Sara Iza & Melissa Hetrick
City of Santa Barbara

Jeremy Pathmanabhan
City of Los Angeles

Ben McFarlane
Hampton Roads Planning District Commission

Erin Girardi
Hampton Roads Sanitation District

Erik Pearson
Hayward Area Shoreline Planning Agency

Lindy Lowe
Port of San Francisco

Jason Warner
Oro Loma Sanitary District

Jackie Zipkin
East Bay Dischargers Authority

Brian Goetz
City of Portsmouth

Beth Eckert, Elizabeth Severt, & Erin Tremblay
Cape Fear Public Utility Authority

Lara Whitely Binder
King County, Washington

Kavita Heyn
Portland Water Bureau

Mitchell Austin
City of Punta Gorda

Questionnaires

Philadelphia Water Department

Portland Water Bureau

Seattle Public Utilities

Tampa Bay Water