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: Upfront (i.e., investment needed to implement)	Costs: Maintenance (i.e., operational costs)	Implementation Timeframe (i.e., amount of time needed to establish and/or reach full capacity)
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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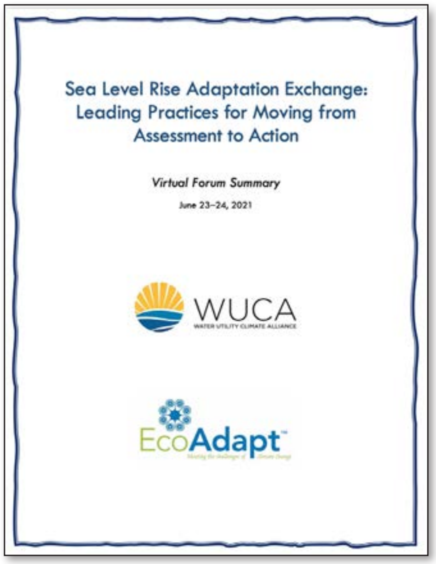

D. Sea Level Rise Adaptation Exchange (Virtual Forum) Summary

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

Name	Affiliation
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