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THE CENTER FOR WATER SECURITY AND COOPERATION

Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities

WATER, SANITATION, AND CLIMATE CHANGE IN THE UNITED STATES SERIES, PART 3

MARCH 2025

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Authors
Shannon McNeeley, Pacific Institute
Morgan Shimabuku, Pacific Institute
Rebecca Anderson, Pacific Institute
Rachel Will, Pacific Institute
Jessica Dery, Pacific Institute

Contributing Authors
Kimberly Lemme, DigDeep
Alyssa Musket, DigDeep
Nora Nelson, DigDeep

DigDeep Story Contributors
Cindy Howe, DigDeep's Navajo Water Project
Kathryn Lucero, DigDeep's Colonias Water Project
Joe Morton, DigDeep's Appalachia Water Project

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ABOUT THE PACIFIC INSTITUTE

The Pacific Institute envisions a world in which society, the economy, and the environment have the water they need to thrive now and in the future. In pursuit of this vision, the Institute creates and advances solutions to the world's most pressing water challenges, such as unsustainable water management and use; climate change; environmental degradation; food, fiber, and energy production for a growing population; and basic lack of access to fresh water and sanitation. Since 1987, the Pacific Institute has cut across traditional areas of study and actively collaborated with a diverse set of stakeholders, including leading policymakers, scientists, corporate leaders, international organizations such as the United Nations, advocacy groups, and local communities. This interdisciplinary and independent approach helps bring diverse groups together to forge effective real-world solutions. More information about the Institute and our staff, directors, funders, and programs can be found at www.pacinst.org.

ABOUT DIGDEEP

DigDeep is a human rights nonprofit working to ensure every person in the United States has access to clean running water and sanitation at home. We have served thousands of families across the country through our award-winning and community-led field projects: the Navajo Water Project (Arizona, New Mexico, and Utah), the Appalachia Water Project (West Virginia), and the Colonias Water Project (Texas). DigDeep is a leading force in US water access research, workforce development, and policy advocacy, underscoring our commitment to addressing the sector's lack of comprehensive data. Notable national reports, including "Closing the Water Access Gap in the United States: A National Action Plan" and "Draining: The Economic Impact of America's Hidden Water Crisis," unveiled the harsh reality that over 2 million people in the US live without a toilet or tap at home, which costs the American economy a staggering $8.6 billion annually. For more information, please visit digdeep.org.

ABOUT CENTER FOR WATER SECURITY AND COOPERATION

The Center for Water Security and Cooperation (CWSC) is a 501(c)(3) nonprofit organization based in Washington, D.C. Founded in 2015, the mission of the CWSC is to advance water security and cultivate cooperation by building a unified body of laws, policies, practices, and standards that ensure the availability of water for current and future generations, and a peaceful, stable, and vibrant global society. Ultimately, the CWSC works to ensure that law and practice guarantee water security and universal access to water and sanitation because without good law those people who have access will lose it, and those who don't, won't ever get it. More information about the CWSC can be found at www.thecwsc.org.

ABOUT THE AUTHORS

Shannon McNeeley

Shannon McNeeley is a Senior Researcher at the Pacific Institute and the Water and Climate Equity Lead. Her work focuses on water and climate equity and justice for frontline communities. This engages an interdisciplinary and cross-cultural co-production approach, incorporating the social and natural sciences along with different ways of knowing to understand human-environment relationships and how people are impacted by and respond to environmental change. Her research has focused on climate change science and policy, water resources and drought preparedness, and climate planning and action, all with a strong focus on supporting those who are overburdened and underresourced through just and equitable solutions. Dr. McNeeley has worked closely for decades with a multitude of different partners, organizations, decision makers, Tribes and Indigenous peoples, and frontline communities bridging technical research with applied decision support information and tools. Prior to joining the Pacific Institute, she was at the North Central Climate Adaptation Science Center at Colorado State University and before that at the National Center for Atmospheric Research. Dr. McNeeley holds a master's degree in international environmental policy from the Middlebury Institute of International Studies at Monterey and a doctoral degree in environmental change and sustainability science, which integrated anthropology, ecology, and climatology, from the University of Alaska Fairbanks.

Morgan Shimabuku

Morgan Shimabuku is a Senior Researcher at the Pacific Institute where she researches a wide range of water management issues, including water equity and access challenges, benefits and tradeoffs of water management strategies, water resilience, and more. Prior to joining the Pacific Institute, Morgan was a senior program manager at an environmental nonprofit in Colorado where she ran residential and commercial water conservation program operations in partnership with municipal water providers. Morgan received a bachelor's degree in environmental studies and geology from Whitman College and a master's degree in geography at the University of Colorado Boulder, where she studied climate change, hydrochemical cycling, and snow hydrology at the Institute of Arctic and Alpine Research.

Rebecca Anderson

Rebecca "Becky" Anderson is a Researcher in Water and Climate Equity at the Pacific Institute, where she focuses on interdisciplinary and collaborative research to advance climate-resilient water and sanitation for frontline communities. Before joining the Pacific Institute, Becky worked as a program manager at a national environmental nonprofit where she supported underresourced communities in developing locally driven, climate-resilient water projects. Her earlier work includes research on agricultural perspectives on water and climate change in the Colorado River Basin, as well as contributions to the review of Groundwater Sustainability Plans in California. Becky holds a bachelor's degree in earth sciences from Ohio State University and a master's degree in geography from Portland State University, where her thesis explored the equity implications of water efficiency tradeoffs.

Rachel Will

Rachel Will joined the Pacific Institute in 2023 as a Researcher in Water and Climate Equity. She co-produces research focused on equitable and climate resilient water systems in rural communities and WASH. Before joining the Pacific Institute, Rachel worked as a regional planner, focusing on social equity and climate resilience projects. She has extensive experience leading and contributing to interdisciplinary research on water equity, environmental justice, and climate resilience issues. Rachel holds a master's in geography from Kent State University, and a doctorate in integrative conservation and geography from the University of Georgia.

Jessica Dery

Jessica Dery is a Research Associate at the Pacific Institute. Her work addresses impediments and incentives for the use of recycled water in agriculture by merging science, policy, and outreach to promote communication and trust. Jessica has worked on a variety of interdisciplinary projects related to water quality and water reuse including agriculture and food safety, water treatment technologies, power generation, and public perception. Her experience includes conducting synthesis research, co-developing outreach products, and working directly with agriculture communities, utilities, and regulatory agencies. She received a bachelor's degree in microbiology from Arizona State University and a master's degree in soil, water, and environmental science from the University of Arizona.

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DEDICATION

We dedicate this report to the communities who
feel the impacts of climate change first and most strongly.

Water is life.

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Glossary*

Acceptable: Water is acceptable if the color, odor, and taste are considered appropriate for personal or domestic use (United Nations 2014), as defined by the user of that water. This standard may vary by a person's culture, gender, and other factors.

Affordable: In general, water service is affordable when a household can afford the cost of essential water and sanitation, including operating and maintaining their own systems, without foregoing other essential goods and services, such as housing, health care, food, and other utilities (Teodoro 2019; Feinstein 2018).

Asset management: The practice of managing capital assets to the appropriate budget for operation, maintenance, and replacement of these assets while delivering optimum service levels (Vedachalam, Male, and Broaddus 2020).

Backsliding: Initial use of the term backsliding in the water sector comes from the Clean Water Act, where it refers to a prohibition of a state's adoption of less stringent water quality guidelines. More recently, DigDeep and US Water Alliance use it in *Closing the Water Access Gap* (2019) to describe a concerning trend in certain states where the number of homes without water and wastewater access has increased. In this report we are examining how climate change is contributing to that trend, and therefore we use backsliding to refer to the process by which a climate phenomenon causes a home or a community to lose access to safe drinking water or a functioning sanitation system (centralized or decentralized/onsite), either temporarily or permanently. We discuss backsliding caused directly or indirectly by climate change through damage or destruction to water and wastewater infrastructure, reduction of water availability at its source in time and quantity, or contamination of water such that it is no longer safe to use.

Climate adaptation technology: The application of technology to decrease vulnerability or increase the resilience of natural or human systems to the impacts of climate change (United Nations Framework Convention on Climate Change 2014).

Climate change: A change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and which is, in addition to natural climate variability, observed over comparable time periods (United Nations Framework Convention on Climate Change 1994).

Community water system: A public water system that supplies water to the same population year-round (US EPA, Office of Water 2015d).

Demand forecasting: The analysis of future water demands to understand spatial and temporal patterns of future water use to optimize system operations, prepare for future expansions or water purchases, or plan for future revenue and expenditures (Pacific Institute and Alliance for Water Efficiency 2012).

Disadvantaged communities (DACs): Under the Safe Drinking Water Act, a "disadvantaged community" is defined as "the service area of a public water system that meets affordability criteria established after public review and comment by the State in which the public water system is located." Per the SDWA, each state is responsible for self-identifying disadvantaged communities. Thus, Clean Water and Drinking Water State Revolving Fund benefits for disadvantaged communities are at the discretion of each state.

*Terms from Part 1 in this series are in white; new terms added specifically for this report are in **yellow.**

Financial capability: The ability of the utility to pay for the capital and operations costs associated with providing safe and reliable water and wastewater services (J. P. Davis and Teodoro 2014).

Frontline communities: Communities that are overburdened and underresourced who face disproportionate, “first and worst” impacts of climate change on their water and sanitation systems or access.

Green infrastructure (GI): Interconnected, built urban ecosystems and infrastructure that function together to provide a variety of benefits for water equity, quantity, biodiversity, air quality, urban heat, recreation, and beautification (Grabowski et al. 2022).

Grey infrastructure: Traditionally engineered solutions and structures for water resource management such as concrete dams, pipes, seawalls, wastewater and water treatment plants.

Human Right to Water and Sanitation (HR2W): Access to water and sanitation is recognized by the United Nations as human rights — fundamental to everyone’s health, dignity, and prosperity. The right to water entitles everyone to have access to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic use. The right to sanitation entitles everyone to have physical and affordable access to sanitation in all spheres of life that is safe, hygienic, secure, socially and culturally acceptable, and provides privacy and ensures dignity (United Nations 2014).

Indigenous peoples: Self-determining societies whose political and cultural foundations pre-exist the formation of the United States, regardless of their recognition status by the US government. Indigenous peoples in the US include the 574 federally recognized Tribes (as of 2023), Native Hawaiians, Pacific and Caribbean Islanders, state-recognized Tribes, and unrecognized Tribes and peoples. More specific terms will be used where the particular government, legal, cultural, or diplomatic situation is referenced. Indigenous peoples’ self-determination can be best respected by using terminology that acknowledges Indigenous governance systems and sovereignty (Status of Tribes and Climate Change Working Group 2021).

Indoor plumbing: The presence of hot-and-cold running water, a shower or bath, and a flush toilet inside the home.

Natural infrastructure (NI): NI means using natural areas and systems or mimicking their processes and functions to provide environmental, economic, and cultural benefits while also supporting climate resilience (The Nature Conservancy, n.d.; National Oceanic and Atmospheric Administration n.d.; Environmental and Energy Study Institute 2019).

Nature-based solutions (NBS): Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges, effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al. 2016).

Physically accessible: For water to be physically accessible it must be available in the home, in sufficient volumes to meet domestic needs, at hot and cold temperatures, 24 hours per day. Similarly, accessible sanitation is when toilets are private, located in a home, safe to visit, and available when needed.

Public water system: A water system that provides drinking water through pipes or other conveyance to at least 15 service connections or an average of 25 people for at least 60 days per year. A public water system may be publicly or privately owned. There are three types of public water systems: community water systems, nontransient noncommunity water systems, and transient noncommunity water systems.

Safe: Drinking water that meets or exceeds standards set forth by the federal Safe Drinking Water Act, and by any additional standards established by individual states where geographically applicable. Safe sanitation means that the waste is separated from humans, and transported, treated, and discharged to the environment where it is not a liability or hazard to human, wildlife, or environmental health.

Sanitation: The conveyance, storage, treatment, and disposal of human waste. This includes toilets, pipes that remove wastewater from the home, and treatment measures (Roller et al. 2019).

Source water: Source water includes natural bodies of water, such as rivers, streams, lakes, reservoirs, springs, and groundwater, that supply water to both public drinking water systems and private wells (US EPA, OW 2015a).

Small water systems: Defined under the Safe Drinking Water Act as community water systems serving 10,000 or fewer people.

Sufficient: The World Health Organization considers 50–100 liters (approximately 13–26 gallons) per person per day to be the minimum necessary to ensure most basic needs are met. However, this amount may not be sufficient for broader uses of water that are necessary for healthy, resilient households and communities; this represents the bare minimum for health purposes (Feinstein 2018; Gleick 1996).

Wastewater: Water that has been used and disposed of, which often contains contaminants such as untreated human waste, sewage, or sludge.

Wastewater services (or systems): The provision of centralized sewer systems and treatment plants, individual septic systems, or other forms of decentralized or onsite systems (Roller et al. 2019).

WASH: The acronym used to refer to water, sanitation, and hygiene, the three basic human requirements for water.

Water access gap: The disparity in access to water and sanitation between most Americans and the communities that still lack access (Roller et al. 2019).

Water efficiency: Efforts that focus on adopting technology, like high-efficiency toilets or drip-irrigation systems, that help to maximize the effectiveness of water use and minimize waste.

Water insecurity: Inadequate or inequitable access to clean, safe, and affordable water for drinking, cooking, sanitation, and hygiene. Water insecurity results from a combination of social and physical conditions, including climate change (Schimpf and Cude 2020).

Water reuse: The practice of reusing wastewater that has not been treated, minimally treated to meet the needs of the intended end use, or fully treated for reuse as drinking water.

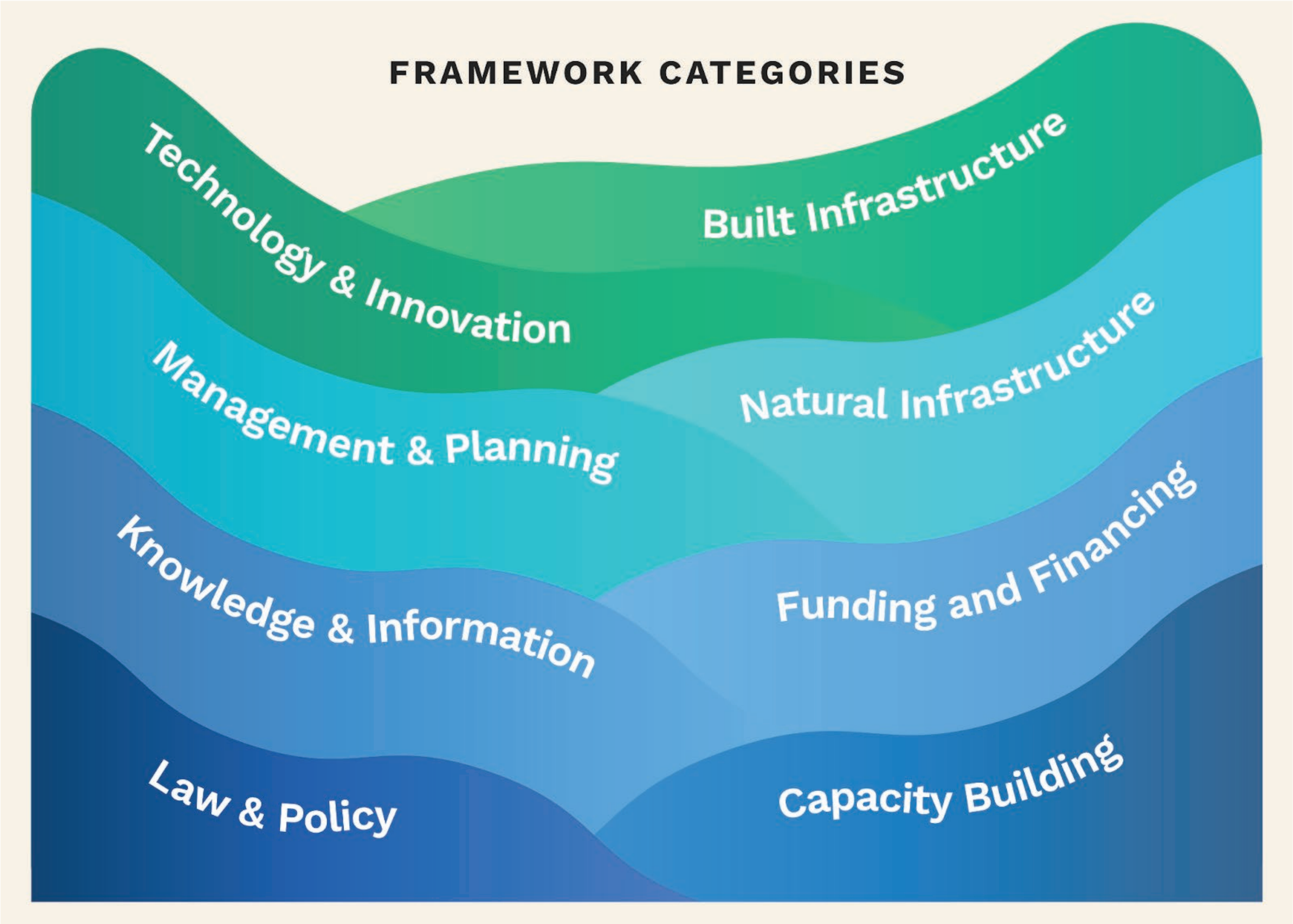
Summary

As climate change intensifies and causes more frequent extreme storms and catastrophic floods, raises sea level, intensifies heat waves and droughts, and sparks more intense wildfires, frontline communities in the US will be at greater risk of losing access to safe, reliable drinking water and functional plumbing (Pacific Institute and DigDeep 2024).

However, frontline communities are resilient, and they are finding ways to overcome the myriad barriers and challenges they face from climate change to create equitable, climate-resilient water and sanitation access and systems. This report aims to identify documented strategies and approaches for achieving equitable, climate-resilient water and sanitation for frontline communities in the US. To do this, we first asked: What is equitable, climate-resilient water and sanitation? What are its characteristics or attributes? And what are communities, organizations, and government agencies doing to achieve it? We developed an eight-part framework to organize, categorize, and communicate the attributes, and then we identified documented strategies and approaches for achieving this goal (Figure S1). In doing this we reviewed academic publications, government and NGO reports, and online resources and tools. In addition, we solicited input from experts in the field at convening events and through online meetings and discussions. We primarily focused on literature, resources, and case examples from the US but drew on literature from non-US contexts when relevant.

This report aims to identify documented strategies and approaches for achieving equitable, climate-resilient water and sanitation for frontline communities in the US.

FIGURE S1. **Framework for Achieving Equitable, Climate-Resilient Water and Sanitation**



Note: The figure depicts the eight categories of climate-resilient and equitable water and sanitation, which serves as the organizing framework for the attributes and corresponding strategies in the report. The visualization incorporates themes and colors from the Pacific Institute's logo, using wave imagery to emphasize the eight framework categories and their interconnections in building equitable, climate-resilient water and sanitation systems.

Figure designed by Pacific Institute and DigDeep, graphic design by Max Olson, DigDeep

While the framework includes the law and policy category, this report does not include this section. We will address this topic in a future report that focuses on law and policy attributes and criteria for identifying laws and policies necessary for achieving equitable, climate-resilient water and sanitation in frontline communities. We also covered law and policies in part 2 of this series titled Law and Policies that Address Equitable, Climate-Resilient Water and Sanitation: Water, Sanitation, and Climate Change in the United States Series, Part 2. Table S1 presents the 31 attributes and their definitions from the seven categories that are addressed in this report.

TABLE S1. Attributes of Equitable, Climate-Resilient Water and Sanitation

ATTRIBUTE TYPE DESCRIPTION	ATTRIBUTES	ATTRIBUTE DEFINITION
BUILT INFRASTRUCTURE		
New or improved built infrastructure aimed at providing equitable, climate-resilient water and sanitation for frontline communities.	Access to water and sanitation infrastructure and services	Frontline communities have access to drinking water and sanitation infrastructure and services that allow them to perform basic everyday tasks and personal hygiene in their homes.
	Built infrastructure performing reliably under a range of climate change impacts	Built infrastructure performs reliably under a wide range of climatic conditions, delivering safe, sufficient, and acceptable water and sanitation for frontline communities.
	Inclusive and climate-resilient siting, design, and construction	Processes for siting, designing, and constructing climate-resilient water and sanitation infrastructure are inclusive and equitable and ensure centering of frontline community values and needs.
	Equitable, climate-resilient operations and maintenance (O&M)	The O&M of water and sanitation build climate resilience and ensure equitable outcomes for frontline communities.
TECHNOLOGY AND INNOVATION		
Innovative technologies help to develop or expand climate resilience and equitable outcomes for water and sanitation access and systems.	Sustainable, climate-resilient, and equitably implemented water technologies	Sustainable, climate-resilient water and sanitation technologies are equitably implemented at the community level, with attention to factors such as local cultures and values, financial context, and ecological benefits.
	Cost-effective water-saving technologies for frontline communities	Water fixture upgrades, water-saving appliances, and water reuse technologies are equitably installed to save water and reduce cost-burden on water, wastewater, and electricity bills of frontline households.
	Sustainable and equitable water and sanitation technologies implemented at the commercial and industrial scale	Sustainable water-use technologies are implemented for significant commercial and industrial users (including agriculturalists, energy suppliers, manufacturers, tourism industries, and others) and increase equity and climate resilience for frontline communities.
	Tested and safe water and sanitation technologies	New, innovative climate-resilient water technologies are tested and evaluated to ensure dependability and safety for frontline communities.

ATTRIBUTE TYPE DESCRIPTION	ATTRIBUTES	ATTRIBUTE DEFINITION
NATURAL INFRASTRUCTURE (NI)		
Nature and natural features and processes are used to build and protect equitable, climate-resilient water and sanitation systems and to help conserve and manage water resources.	Constraints for NI implementation removed	Governance, policy, legal, and financial constraints for NI implementation are addressed and removed through context-specific practices to support equitable climate resilience.
	Centering communities in NI planning	Communities, community benefits, and equity are included and centered in NI planning for climate resilience.
	NI projects proactively removing displacement risks	Potential displacement of communities in all NI programs, policies, and projects are identified and removed.
	NI benefits valued for achieving equitable climate resilience	Context-specific approaches to the valuation of NI for equitable, climate-resilient water and sanitation are used in decision making.
MANAGEMENT AND PLANNING		
Equity is centered in how environmental protections, community input, financial sustainability, climate impacts and risks, multi-sector coordination, and monitoring and evaluation are incorporated into planning and management of water and sanitation access.	Source water protections incorporated into water, sanitation, and climate plans and programs	Source water and other environmental protections are part of water and sanitation planning and management to increase frontline communities' resilience to climate change.
	Frontline communities centered in climate, water, and sanitation planning and management	Equitable involvement and empowerment of community members in planning and management are reflected by centering frontline communities' priorities.
	Water and sanitation providers financially sound in the face of climate change	The financial health of utilities and cities is supported by proactive, long-term planning and management strategies that result in accessible, affordable, and climate-resilient water and sanitation for frontline communities.

ATTRIBUTE TYPE DESCRIPTION	ATTRIBUTES	ATTRIBUTE DEFINITION
	Water and sanitation systems prepared for climate disasters and inequitable impacts	There is regular planning and management for climate disasters and inequitable climate disruptions to water and sanitation systems.
	Cross-sectoral coordination to achieve equitable, climate-resilient water and sanitation	Equitable and climate-resilient management and planning efforts are coordinated across sectors, departments, agencies, plans, and different scales of government.
	Equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness	Managers and planners continually monitor and evaluate water and sanitation to achieve equitable and climate-resilient outcomes for frontline communities.
FUNDING AND FINANCING		
Adequate, sustainable, equitable funding, financing, and disaster insurance strategies for frontline communities to build, adapt, maintain, and restore climate-resilient water and sanitation.	Funding and financing for climate-resilient water and sanitation infrastructure	Climate-resilient infrastructure projects for water and sanitation systems serving frontline communities and households can obtain and sustain funding or financing for planning and infrastructure.
	Funding and assistance for climate-resilient O&M	Climate-resilient O&M for water and sanitation systems in frontline communities have adequate and sustainable funding and assistance.
	Funding and financing for climate disaster preparedness, mitigation, response, and restoration of water and sanitation	Frontline communities have access to adequate funding, financing, and disaster insurance for disaster preparation, response, and restoration so that water and sanitation can be equitably restored after a climate disaster.
	Funding and financing for alternative approaches to equitable, climate-resilient water and sanitation	Nature-based solutions (NBS), green infrastructure (GI), and water efficiency and reuse have sustainable, adequate funding sources to be implemented at scale in support of climate-resilient water and sanitation for frontline communities.
	Affordable climate-resilient water and sanitation for households	Frontline communities can afford climate-resilient water and sanitation in their homes without compromising their ability to pay for other necessities like food, housing, health care, and transportation.

ATTRIBUTE TYPE DESCRIPTION	ATTRIBUTES	ATTRIBUTE DEFINITION
KNOWLEDGE AND INFORMATION		
Equitable, transparent, accessible integration and application of technical and community knowledges,[1] data, and information are needed to achieve equitable, climate-resilient water and sanitation.	Usable water and climate data at appropriate scales for communities	Water resource, climate, and other relevant data are at the appropriate temporal and spatial scales and readily accessible to decision makers, water managers, and frontline communities.
	Inclusivity in the use of climate data, projections, and assessments	Climate data and projections are used with the inclusion of frontline communities to inform water and sanitation and water resources risk assessments, planning, management, and development.
	Incorporation of local and technical knowledges and ways of knowing	Local, place-based knowledges, Indigenous knowledges, and different ways of knowing and observing are equally respected, supported, and incorporated with technical data and information for equitable, climate-resilient water and sanitation.
	Equitable data and information translation, communication, and dissemination	Data and information collection centers the needs and perspectives of frontline communities and is shared openly and in culturally appropriate formats and languages that are accessible to frontline communities.
CAPACITY BUILDING		
Water managers, communities, and households are equipped with the technical, managerial, and financial capacity to equitably engage communities and adapt to climate change.	Climate-literate, robust, and representative water and sanitation workforce	Water and sanitation workforce in frontline communities is climate-literate, robust and representative of the communities being served.
	Community empowerment in water and climate decision making	Communities are supported and have increased capacity for inclusive, equitable, and culturally appropriate participation in climate, water, and sanitation decision making.
	Capacity to work with interdependent sectors for climate resilience	People managing water and sanitation systems have the ongoing capacity to coordinate with other people in sectors with whom they are interdependent for climate resilience.
	Technical, managerial, and financial (TMF) skills for equitable climate resilience	Water managers are empowered with the TMF and leadership skills to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.
***Law and Policy: the law and policy attributes will be addressed in a forthcoming report in 2025**		

1 Although "knowledge" is considered a singular, uncountable noun, we intentionally use the plural "knowledges" to indicate that there is no one monolithic knowledge to understand and address complex issues at the nexus of water and climate equity and that problems and solutions to address climate change require many types of knowledges from myriad disciplines and sources, including local and Indigenous knowledges.

This report contains numerous documented efforts of ways that frontline communities are making progress toward equitable, climate-resilient water and sanitation. Built infrastructure is being adapted to better withstand the impacts of extreme storms, floods, and drought. Technologies and innovations are being designed and deployed in remote, hard-to-reach communities to deliver climate-resilient water and sanitation to homes for the first time. Natural infrastructure strategies are being used to enhance the climate resilience of water and sanitation by helping recharge aquifers and attenuate floodwaters, for example. Water managers and planners are incorporating climate resilience and centering frontline communities in efforts to deliver equitable, climate-resilient water and sanitation access to all. Frontline communities are overcoming barriers to accessing the financial resources that they need to pay for climate adaptation of water and sanitation or recover and respond to climate disasters. Climate and water knowledge and information from government agencies, water managers, local experts, and climate scientists are being integrated with place-based knowledges to ensure frontline communities and people in positions of power and authority can understand and access the data and information they need for decision making. The capacity of water and sanitation systems staff and decision makers is growing to better center the needs of frontline communities, educate and support the water and sanitation sector workforces in improving climate-resilience, and build connections with interdependent sectors.

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Here we summarize key findings on more than 100 strategies across the seven categories documented in this report. The strategies and approaches are not for a single audience. Rather, they were developed by and for frontline communities, their supporters (e.g., community-based organizations or nonprofits), water resource managers, water and wastewater utilities, policy and law makers, and Tribal, federal, state, and local governments to advance equitable, climate-resilient water and sanitation in the US. These strategies are a sampling of diverse approaches without prescribing one-size-fits-all solutions. No doubt there are numerous others that were not included or have not yet been documented.

The strategies outlined in this report are expected to remain relevant over time, though some are more time-bound and may not be available in the future.[2] This is particularly relevant for funding and financing mechanisms, which are likely to shift at the federal level with political and administrative changes. Notably, the research and writing for this report was completed in 2024. However, as we are preparing the document for publication in January 2025, some federal resources and funding mechanisms herein became unavailable following the White House administration change on January 20th. Wherever possible, archived versions of websites and documents have been provided, although additional resources may become unavailable after this report is published.

Along with the more than 100 strategies, the report includes numerous case examples of equitable and climate-resilient water and sanitation from across the country, including three place-based stories of DigDeep's work with individuals and communities from Navajo Nation (Section 5.5), Appalachia (Section 8.6), and *colonias* along the US-Mexico border (Section 10.5).


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2 The report reflects strategies available as of January 2025.

BUILT INFRASTRUCTURE

The built infrastructure attributes describe new or improved built infrastructure aimed at providing equitable, climate-resilient water and sanitation for frontline communities. Each built infrastructure attribute and the respective descriptions are listed in Table S2, and the strategies and approaches to achieve them follow.

TABLE S2. Built Infrastructure Attributes

BUILT INFRASTRUCTURE	
Attributes	**Attribute Definition**
Access to water and sanitation infrastructure and services	Frontline communities have access to drinking water and sanitation infrastructure and services that allow them to perform basic everyday tasks and personal hygiene in their homes.
Built infrastructure performing reliably under a range of climate change impacts	Built infrastructure performs reliably under a wide range of climatic conditions, delivering safe, sufficient, and acceptable water and sanitation for frontline communities.
Inclusive and climate-resilient siting, design, and construction	Processes for siting, designing, and constructing climate-resilient water and sanitation infrastructure are inclusive and equitable and ensure centering of frontline community values and needs.
Equitable, climate-resilient operations and maintenance (O&M)	The O&M of water and sanitation build climate resilience and ensure equitable outcomes for frontline communities.

1. **Access to water and sanitation infrastructure and services. Strategies include:**
   a. initiate and support community-led water and sanitation infrastructure projects with nonprofit organizations and other entities dedicated to closing the water and sanitation access gap; and
   b. create local programs to connect households and communities with water and sanitation systems at risk from climate impacts to more climate-robust centralized water and/or sanitation systems.

2. **Built infrastructure performing reliably under a range of climate change impacts. Strategies include:**
   a. create tools and frameworks for water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure;
   b. improve water supply reliability through water reuse, fixing leaks in distribution systems, recharging aquifers (with floodwater where possible), and deepening groundwater wells;
   c. consider consolidation through a range of partnership forms to improve supply reliability during climate emergencies;
   d. elevate coastal infrastructure to protect infrastructure from sea level rise;

e. adapt infrastructure to be better prepared for wildfire by adding backflow prevention devices on service lines, installing meters with the ability to automatically shutoff and keeping plastic infrastructure away from heat sources; and

f. when necessary, relocate community water stations and other infrastructure to protect them from damage and destruction.

3. **Inclusive and climate-resilient siting, design, and construction. Strategies include:**

   a. create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience; and

   b. change existing or establish new processes and policies for inclusive and equitable siting and design of climate-resilient water and sanitation infrastructure with direct input from frontline communities.

4. **Equitable, climate-resilient O&M. Strategies include:**

   a. identify specific O&M tasks that must be performed or adapted to protect infrastructure from climate impacts;

   b. put emergency response systems in place to help operators perform necessary actions during climate emergencies;

   c. work with technical assistance providers to perform regular O&M to ensure infrastructure remains in good condition to withstand climate disruptions;

   d. use materials, trainings, and tools from technical assistance providers and other supporting entities to learn about tasks needed for improving climate resilience; and

   e. engage directly with frontline communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.

To achieve equitable, climate-resilient water and sanitation is to close the water and sanitation access gap in the US; built infrastructure, like dams, water distribution systems, and treatment plants must be adapted to ensure that they can reliably function under an increasingly broad range of climate-related conditions. Through these efforts, the engineers, contractors, utilities, and other agencies that often lead the construction processes need to ensure that siting, design, and construction of water and sanitation infrastructure address climate resilience and do so equitably by including and centering frontline communities throughout the process. Finally, the ongoing O&M of water and sanitation systems needs to be made more inclusive and equitable and must help build climate resilience for communities.

TECHNOLOGY AND INNOVATION

The technology and innovation attributes describe how innovative technologies help to develop or expand climate resilience and equitable outcomes for water and sanitation access and systems. Each technology and innovation attribute and the respective descriptions are listed in Table S3, and the strategies and approaches to achieve them follow.

TABLE S3. Technology and Innovation Attributes

TECHNOLOGY AND INNOVATION	
Attributes	Attribute Definition
Sustainable, climate-resilient, and equitably implemented water technologies	Sustainable, climate-resilient water and sanitation technologies are equitably implemented at the community level, with attention to factors such as local cultures and values, financial context, and ecological benefits.
Cost-effective water-saving technologies for frontline communities	Water fixture upgrades, water-saving appliances, and water reuse technologies are equitably installed to save water and reduce cost-burden on water, wastewater, and electricity bills of frontline households.
Sustainable and equitable water and sanitation technologies implemented at the commercial and industrial scale	Sustainable water-use technologies are implemented for significant commercial and industrial users (including agriculturalists, energy suppliers, manufacturers, tourism industries, and others) and increase equity and climate resilience for frontline communities.
Tested and safe water and sanitation technologies	New, innovative climate-resilient water technologies are tested and evaluated to ensure dependability and safety for frontline communities.

1. **Sustainable, climate-resilient, and equitably implemented water technologies. Strategies include:**
    a. engage with stakeholders, with special attention to local values and cultures, when designing and implementing water and sanitation technologies and innovations;
    b. develop respectful partnerships between universities, technology companies, and frontline communities to co-develop technologies tailored to communities' needs;
    c. implement knowledge sharing about climate-resilient technologies, especially to communities with unequal access to information; and
    d. integrate equity-centered frameworks in the planning and design of technologies that consider environmental, economic, and social equities.

2. **Cost-effective water-saving technologies for frontline communities. Strategies include:**
    a. develop water efficiency programs tailored to low-income residents to ensure that they benefit from cost-saving technologies;
    b. partner with community-based organizations to build trust within frontline communities and enhance participation in tailored low-income water efficiency programs; and
    c. leverage corporate investments to implement water and cost saving technologies in frontline communities, such as affordable housing complexes.

3. **Sustainable and equitable water and sanitation technologies implemented at the commercial and industrial scale. Strategies include:**
    a. establish policies that promote the commercial adoption of water technologies offering broad climate resilience benefits for communities;
    b. build partnerships between water and wastewater utilities and industries to implement large-scale technologies, such as water reuse systems;
    c. design and implement commercial and industrial water technologies and innovations collaboratively with nongovernmental organizations (NGOs) and technology companies; and
    d. utilize existing support programs to scale up the implementation of innovations across commercial and industrial sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies.

4. **Tested and safe water and sanitation technologies. Strategies include:**
    a. engage the community during the pilot phase of a new technology to understand local conditions, values, cultures, and needs before widespread implementation; and
    b. apply a systematic and integrated management approach, such as Integrated Water Resource Management, to prioritize the safe and effective deployment of climate-resilient innovations within the intricate framework of water and sanitation systems.

Water and sanitation technologies and innovations offer significant potential to enhance the climate resilience of frontline communities, but their success depends on equitable design and implementation. These technologies must be culturally appropriate, socially acceptable, affordable, and sustainable, while also addressing the specific barriers faced by low-income and historically marginalized groups. Strategies like robust stakeholder engagement, equity-centered frameworks, and partnerships are critical to ensure that frontline communities benefit from technology and innovations. In addition, water efficiency and reuse technologies can reduce costs for frontline communities, although challenges like high upfront costs persist. Programs that involve direct-install services, community-based partnerships, and corporate investments offer pathways to overcome these barriers. Beyond residential use, commercial and industrial water users have a role in advancing equity and resilience by adopting technologies that reduce water demand and improve water quality, which can be facilitated through policies, partnerships, and support programs. Finally, the effective deployment of these innovations requires a deep understanding of local contexts and a systematic planning approach to ensure that technologies address root causes of vulnerability and avoid maladaptation.

NATURAL INFRASTRUCTURE

The natural infrastructure (NI) attributes describe how nature and natural features and processes are used to build and protect equitable, climate-resilient water and sanitation systems and to help conserve and manage water resources. Each natural infrastructure attribute and the respective descriptions are listed in Table S4, and the strategies and approaches to achieve them follow.

TABLE S4. Natural Infrastructure Attributes

NATURAL INFRASTRUCTURE (NI)	
Attributes	**Attribute Definition**
Constraints for NI implementation removed	Governance, policy, legal, and financial constraints for NI implementation are addressed and removed through context-specific practices to support equitable climate resilience.
Centering communities in NI planning	Communities, community benefits, and equity are included and centered in NI planning for climate resilience.
NI projects proactively removing displacement risks	Potential displacement of communities in all NI programs, policies, and projects are identified and removed.
NI benefits valued for achieving equitable climate resilience	Context-specific approaches to the valuation of NI for equitable, climate-resilient water and sanitation are used in decision making.

1. **Constraints for NI implementation removed. Strategies include:**
   a. create integrated NI management plans to coordinate knowledge and information exchange, planning, and management across departments, sectors, and jurisdictions;
   b. implement policies to overcome constraints to equitable NI project outcomes;
   c. form strong partnerships, coalitions, and interdisciplinary working groups to address conflicts and build NI project support and consensus; and
   d. use innovative and diverse funding solutions appropriate to the local context.

2. **Centering communities in NI planning. Strategies include:**
   a. clearly define justice and equity in NI projects;
   b. ensure communities experiencing injustice have a say throughout the planning process using two-way communication;
   c. incorporate transparency, trust building, and mutual learning in community engagement; and
   d. partner with trusted local institutions to engage hard-to-reach groups.

3. **NI projects proactively removing displacement risks. Strategies include:**
   a. utilize and adapt existing toolkits to identify local risk factors for displacement and to evaluate the strength of anti-displacement strategies;

b. implement locally appropriate and feasible anti-gentrification and displacement policies prior to project construction; and

c. co-create equity scorecards with residents and other stakeholders to evaluate how well an NI project mitigates gentrification and displacement.

4. **NI benefits valued for achieving equitable climate resilience. Strategies include:**

a. utilize comprehensive valuation models that center climate resilience, human and ecological well-being, and impacts for multiple sectors and stakeholders;

b. incorporate equity-centered guidelines alongside valuation models to understand the distribution of tradeoffs and benefits for frontline communities; and

c. incorporate non-market-based valuations and recommendations that center equity.

NI has great potential to enhance the climate resilience of water and sanitation systems. However, they must be equitably designed and implemented. Barriers to NI implementation can prevent their uptake at a greater scale but can be overcome through strategies such as integrated management plans, the formation of strong partnerships, coalitions, and interdisciplinary working groups, and the use of comprehensive valuation models. Because NI projects come with tradeoffs, care is needed to ensure that equity and community benefits are central to decision making and that tradeoffs do not disproportionately accrue to frontline communities and underserved residents. Solutions such as centering impacted communities in decision making, building trust with local communities, and implementing anti-displacement policies are critical to ensuring that frontline communities benefit from these projects. Ultimately, attention to local context and impacted communities is critical to achieving equitable and climate-resilient water and sanitation.


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MANAGEMENT AND PLANNING

These attributes describe how equity is centered in the management and planning of environmental protections, community input, financial sustainability, climate impacts and risks, multi-sector coordination, and monitoring and evaluation. Each management and planning attribute and the respective descriptions are listed in Table S5, and the strategies and approaches to achieve them follow.

TABLE S5. Management and Planning Attributes

MANAGEMENT AND PLANNING	
Attributes	**Attribute Definition**
Source water protections incorporated into water, sanitation, and climate plans and programs	Source water and other environmental protections are part of water and sanitation planning and management to increase frontline communities' resilience to climate change.
Frontline communities centered in climate, water, and sanitation planning and management	Equitable involvement and empowerment of community members in planning and management are reflected by centering frontline communities' priorities.
Water and sanitation providers financially sound in the face of climate change	The financial health of utilities and cities is supported by proactive, long-term planning and management strategies that result in accessible, affordable, and climate-resilient water and sanitation for frontline communities.
Water and sanitation systems prepared for climate disasters and inequitable impacts	There is regular planning and management for climate disasters and inequitable climate disruptions to water and sanitation systems.
Cross-sectoral coordination to achieve equitable, climate-resilient water and sanitation	Equitable and climate-resilient management and planning efforts are coordinated across sectors, departments, agencies, plans, and different scales of government.
Equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness	Managers and planners continually monitor and evaluate water and sanitation to achieve equitable and climate-resilient outcomes for frontline communities.

1. **Source water protections incorporated into water, sanitation, and climate plans and programs. Strategies include:**

    a. use remediation projects as an opportunity to implement NI that protects source water quality for frontline communities;

    b. include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security;

c. collaborate with frontline communities, scientists, and managers to co-produce tools, plans, and programs that safeguard source water; and

d. integrate education, awareness, and support for private well water quality testing into management frameworks.

2. **Frontline communities centered in climate, water, and sanitation planning and management. Strategies include:**

    a. begin with a visioning stage to incorporate frontline communities' insights into climate-resilient water and sanitation planning from the outset;

    b. integrate community-based organizations into climate adaptation and water and sanitation planning and management efforts to improve the representation of marginalized groups;

    c. foster collaborative research partnerships that act as boundary organizations, connecting frontline communities with regional and national planning efforts while developing locally tailored resources for self-reliance; and

    d. provide financial resources, such as stipends, to empower individuals and communities to meaningfully engage in management and planning processes.

3. **Water and sanitation providers financially sound in the face of climate. Strategies include:**

    a. include asset management in long-term planning that takes into consideration climate change impacts to water and wastewater infrastructure;

    b. conduct demand forecasting to help ensure that future water demand projections account for both climate change scenarios and efficiency initiatives; and

    c. employ proactive rate setting to prevent reactive rate increases that could render water and sanitation services unaffordable for frontline communities.

4. **Water and sanitation systems prepared for climate disasters and inequitable impacts. Strategies include:**

    a. develop emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for frontline communities;

    b. include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected;

    c. incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for frontline communities;

    d. participate in trainings and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions; and

    e. integrate resilience hubs into climate, water, and sanitation planning and management to strengthen community resilience and social equity after climate disasters.

5. **Cross-sectoral coordination to achieve equitable, climate-resilient water and sanitation. Strategies include:**
    a. align management and planning structures strategically, using frameworks like Integrated Water Resource Management and One Water as foundations for equitable, resilient practices;
    b. include interagency working groups in climate, water, and sanitation plans to clarify sector roles in climate disruption responses, establish coordinated technical assistance programs for frontline communities, and promote climate resilience and equity;
    c. integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together; and
    d. participate in specialized trainings and exercises to learn how to address climate impacts on frontline communities equitably and collaboratively across sectors.
6. **Equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness. Strategies include:**
    a. involve community members and community-based organizations in the design and implementation of monitoring frameworks to promote inclusive, attainable, and locally informed processes;
    b. allocate a specific budget for monitoring and evaluation when designing programs and plans to ensure that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives;
    c. use equity-focused indicators to track climate resilience outcomes of water and sanitation plans and programs effectively across communities; and
    d. apply monitoring and evaluation to both new initiatives and existing practices to comprehensively address systemic inequities and enhance accountability.

Protecting the source water for overburdened and underserved communities is critical as these communities face historical challenges to access drinking water and sanitation that are now exacerbated by climate change. Actively engaging frontline communities helps to ensure that their needs, cultures, and priorities are centered in planning processes and management frameworks. Water and sanitation providers can implement strategies like asset management, proactive rate setting, and demand forecasting to maintain financial stability and provide affordable services for low-income populations in the face of climate change. Additionally, integrating disaster preparedness into planning is key, and incorporating community input helps identify vulnerabilities and design adaptive strategies tailored to communities' needs. Cross-sector coordination dismantles silos and fosters collaboration among stakeholders, enhancing the effectiveness and climate-resilient outcomes of water and sanitation plans and initiatives. Finally, embedding monitoring and evaluation frameworks within climate, water, and sanitation strategies promotes accountability and transparency and tracks progress toward equitable water access, ultimately improving resilience for frontline communities.

FUNDING AND FINANCING

The funding and financing attributes describe adequate, sustainable, equitable funding and financing and disaster insurance strategies for frontline communities to build, adapt, maintain, and restore climate-resilient water and sanitation systems. Each funding and financing attribute and the respective descriptions are listed in Table S6, and the strategies and approaches to achieve them follow.

TABLE S6. Funding and Financing Attributes

FUNDING AND FINANCING	
Attributes	**Attribute Definition**
Funding and financing for climate-resilient water and sanitation infrastructure	Climate-resilient infrastructure projects for water and sanitation systems serving frontline communities and households can obtain and sustain funding or financing for planning and infrastructure.
Funding and assistance for climate-resilient operations and maintenance (O&M)	Climate-resilient O&M for water and sanitation systems in frontline communities have adequate and sustainable funding and assistance.
Funding and financing for climate disaster preparedness, mitigation, response, and restoration of water and sanitation	Frontline communities have access to adequate funding, financing, and disaster insurance for disaster preparation, response, and restoration so that water and sanitation can be equitably restored after a climate disaster.
Funding and financing for alternative approaches to equitable, climate-resilient water and sanitation	Nature-based solutions (NBS), green infrastructure (GI), and water efficiency and reuse have sustainable, adequate funding sources to be implemented at scale in support of climate-resilient water and sanitation for frontline communities.
Affordable climate-resilient water and sanitation for households.	Frontline communities can afford climate-resilient water and sanitation in their homes without compromising their ability to pay for other necessities like food, housing, health care, and transportation.

1. **Funding and financing for climate-resilient water and sanitation infrastructure. Strategies include:**
   a. increase the amount of funding available through federal and state programs, including the Clean Water State Revolving Fund (CWSRF) and Drinking Water State Revolving Fund (DWSRF), that can be used to build and adapt climate-resilient water and sanitation infrastructure;
   b. ensure that funding and financing are accessible and do not have barriers for frontline communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure;
   c. enact policies that ensure frontline communities are receiving an equitable amount of benefits from climate and infrastructure funding;

   d. implement technical assistance programs to address barriers experienced by frontline communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure; and
   e. offer programs to help construct climate-resilient, decentralized water and sanitation infrastructure and/or to connect homes and communities with decentralized infrastructure to more climate-robust centralized systems.

2. **Funding and assistance for climate-resilient O&M. Strategies include:**
   a. create and fund federal and state grant programs that explicitly name climate resilience and O&M as funding priorities for water and sanitation systems;
   b. offer O&M as an activity available through technical assistance providers; and
   c. fund and train technical assistance providers on climate-resilient O&M.

3. **Funding and financing for climate disaster preparedness, response, and restoration of water and sanitation. Strategies include:**
   a. increase funding available through federal community preparedness and climate hazard mitigation programs and expand access to these programs for frontline communities;
   b. expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities;
   c. ensure that climate disaster response and recovery efforts do not exacerbate or increase wealth inequality;
   d. fill gaps in government aid with local efforts by grassroots coalitions and NGOs to create local financing options and climate disaster recovery; and
   e. provide households at risk of sewer backups or damage to their onsite water or sanitation systems with insurance and funding assistance to recover from climate disasters.

4. **Funding and financing for alternative approaches to equitable, climate-resilient water and sanitation. Strategies include:**
   a. increase the amount of funding available through federal and state programs that can be used to design and build alternative approaches to climate resilience;
   b. ensure that funding and financing for alternative approaches are accessible and do not have barriers for frontline communities to identify, apply for, and use the assistance;
   c. enact policies that ensure frontline communities are receiving an equitable amount of benefits of funding for alternative approaches; and
   d. offer programs to incentivize or pay for water efficiency upgrades in households in frontline communities.

5. **Affordable climate-resilient water and sanitation for households. Strategies include:**
   a. create and offer utility customers assistance programs and other affordability interventions like leak detection and repair for income-qualified households;

b. reinstate and fund federal water and wastewater assistance programs that ensure customers of all water and wastewater utilities have access to financial assistance for paying their utility bills; and

c. enact laws at the state, local, or federal level that prevent water disconnections during extreme weather or climate events.

Funding and financing are required for all the work necessary to build and adapt water and sanitation infrastructure, update and improve O&M to support climate resilience, prepare for climate disasters, respond equitably and effectively when they occur, apply alternative approaches to climate resilience in frontline communities, and ensure that water and sanitation remain affordable. While financial assistance is not a silver bullet to advancing equitable, climate-resilient water and sanitation for frontline communities in the US, it is critical for supporting major, necessary infrastructure transformation. It is also important to make funding for disaster preparedness, response, recovery, and disaster insurance equitably accessible, so that frontline communities can prepare for, survive, and recover from the inevitable climate impacts to come. If financial assistance is provided equitably for climate resilience of water and sanitation, it will help prevent future affordability burdens on communities and households already struggling to pay for their access to water and sanitation.

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KNOWLEDGE AND INFORMATION

The knowledge and information attributes focus on how equitable, transparent, accessible integration and application of technical and community knowledges, data, and information are needed to achieve equitable, climate-resilient water and sanitation. Each knowledge and information attribute and the respective descriptions are listed in Table S7, and the strategies and approaches to achieve them follow.

TABLE S7. Knowledge and Information Attributes

KNOWLEDGE AND INFORMATION	
Attributes	**Attribute Definition**
Usable water and climate data at appropriate scales for communities	Water resource, climate, and other relevant data are at the appropriate temporal and spatial scales and readily accessible to decision makers, water managers, and frontline communities.
Inclusivity in the use of climate data, projections, and assessments	Climate data and projections are used with the inclusion of frontline communities to inform water and sanitation and water resources risk assessments, planning, management, and development.
Incorporation of local and technical knowledges and ways of knowing	Local, place-based knowledges, Indigenous knowledges, and different ways of knowing and observing are equally respected, supported, and incorporated with technical data and information for equitable, climate-resilient water and sanitation.
Equitable data and information translation, communication, and dissemination	Data and information collection centers the needs and perspectives of frontline communities and is shared openly and in culturally appropriate formats and languages that are accessible to frontline communities.

1. **Usable water and climate data are at appropriate scales for communities. Strategies include:**
    a. focus water and climate research and information on community needs and values instead of those of outsiders;
    b. make sure data and tools are scaled appropriately and meaningfully at the community level whenever possible;
    c. make data and information free, understandable, and easily accessible;
    d. use a co-production approach to ground technical data and information in local knowledge and expertise; and
    e. increase access to internal and trusted external support and expertise to increase capacity and overcome technical, legal, and policy barriers.

2. **Inclusivity in the use of data, projections, and assessments. Strategies include:**
    a. use an end-to-end co-production approach in assessing climate risks to include frontline communities in design, research, and development of decision-support information and tools;
    b. apply citizen science as an inclusive strategy for engaging locals in data gathering and monitoring to incorporate local observers and empower communities to build climate-resilience;
    c. ensure adequate funding for communities to engage in knowledge co-production and sharing; and
    d. recognize and address barriers and capacity constraints at the outset of any water and climate risk assessments by providing culturally appropriate and community-centered technical assistance.

3. **Incorporation of local and technical knowledges and ways of knowing. Strategies include:**
    a. ensure that local experts have consultation and leadership roles in any community research, data gathering, and monitoring efforts;
    b. use collaborative, participatory, and/or co-production approaches for equitable incorporation or integration in knowledge creation and sharing; and
    c. use appropriate protocols and agreements to protect local knowledge and communities.

4. **Equitable data and information translation, communication, and dissemination. Strategies include:**
    a. present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals, because research suggests that audiences tend to reject fear-based messages;
    b. connect climate issues to real-world concerns that people already care about by framing challenges within their local cultural, socioeconomic, or geographic context, as well as aligning with their values and worldviews;
    c. embrace uncertainty by focusing on what is known and highlighting scientific consensus, while remaining open to new and improved information; and
    d. utilize storytelling to effectively convey data, acknowledging and respecting the emotions and psychology of the target audience while validating their experiences.

By valuing and incorporating diverse perspectives and knowledges, barriers can be overcome through inclusive governance structures and collaborative partnerships. Ultimately, these approaches not only enhance the ecological and social resilience of communities but also foster a deeper understanding and respect for the interconnectedness between humans and their environment. Integrating local, place-based knowledges and Indigenous knowledges with technical data and information is crucial for achieving equitable, climate-resilient water and sanitation systems in the US. This, along with accessible and usable water and climate data at appropriate temporal and spatial scales; inclusivity in the use of climate data for risk assessments; equitable data and information translation, communication, and dissemination can help build capacity for frontline communities to achieve equitable, climate-resilient water and sanitation.

CAPACITY BUILDING

The capacity building attributes describe how water managers, communities, and households are equipped with the technical, managerial, and financial capacity to equitably engage communities and adapt to climate change. Each capacity building attribute and the respective descriptions are listed in Table S8, and the strategies and approaches to achieve them follow.

TABLE S8. Capacity Building Attributes

CAPACITY BUILDING	
Attributes	**Attribute Definition**
Climate-literate, robust, and representative water and sanitation workforce	Water and sanitation workforce in frontline communities is climate-literate, robust and representative of the communities being served.
Community empowerment in water and climate decision making	Communities are supported and have increased capacity for inclusive, equitable, and culturally appropriate participation in climate, water, and sanitation decision making.
Capacity to work with interdependent sectors for climate resilience	People managing water and sanitation systems have the ongoing capacity to coordinate with other people in sectors with whom they are interdependent for climate resilience.
Technical, managerial, and financial (TMF) skills for equitable climate resilience	Water managers are empowered with the TMF and leadership skills to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.

1. **Climate-literate, robust, and representative water and sanitation workforce. Strategies include:**
    a. take advantage of national and local climate adaptation training and education programs to increase climate literacy in the water and sanitation workforce;
    b. provide opportunities for recognition and networking for upcoming utility leaders, especially those from underrepresented groups; and
    c. educate students about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.
2. **Community empowerment in water and climate decision making. Strategies include:**
    a. build trust between communities and water and wastewater utilities by promoting transparency, inclusivity, and community engagement, leveraging tools like the River Network and WaterNow Alliance's Building Blocks of Trust;
    b. co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with frontline communities using community-based participatory research and an asset-based approach; and
    c. develop coalitions of community members, community-based organizations, and other NGOs to advance community-driven water and sanitation policies.

3. **Capacity to work with interdependent sectors for climate resilience. Strategies include:**
   a. leverage existing tools and resources, such as the Environmental Protection Agency's (EPA) Community-Based Water Resilience Guide, to understand interdependent sectors and initiate conversations;
   b. foster partnerships between neighboring water and wastewater utilities to provide mutual aid and support to recover from climate disruptions; and
   c. develop local or regional climate adaptation initiatives that foster education, information sharing, and communication across sectors to enhance preparation and response to climate impacts.

4. **Technical, managerial, and financial (TMF) skills for equitable climate resilience. Strategies include:**
   a. require TMF trainings for water system board members to support compliance with regulations, such as the Safe Drinking Water Act;
   b. establish formal and informal social networks among underserved systems to share information and resources for overcoming capacity challenges and better prepare for climate impacts;
   c. consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity; and
   d. take advantage of leadership training programs to develop leaders equipped with TMF skills to advance climate-resilient strategies.


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Building water managers' and communities' capacities is essential for achieving equitable and climate-resilient water and sanitation in frontline communities. By fostering leadership, climate-literacy, and representation in the water and sanitation workforce through targeted training, networking, and educational opportunities, water and climate management and planning processes can be made more inclusive and responsive to local needs. Water and wastewater utilities can build trust with communities and prioritize participatory approaches to help ensure frontline communities are empowered to participate in decision making and co-develop climate-resilient strategies. Additionally, building capacity for cross-sector collaboration through partnerships between neighboring utilities, developing local or regional climate adaption initiatives, and using existing resources and tools to spark conversations can help frontline communities be more prepared to respond to climate disruptions to water and sanitation. Finally, investing in technical, managerial, and leadership skills through trainings, formal and informal networks, and consolidation and/or regionalization can equip water and sanitation managers to navigate the complexities of climate challenges. Together, these approaches not only build resilience but also address systemic inequities, laying the groundwork for a more climate-resilient future for frontline communities.

While this report provides ample evidence that there is a large and growing body of knowledge surrounding water, climate change, and equity, through our research we identified several gaps that indicate a need for future research and documentation at the nexus of water, climate, and equity.

These include:

- A comprehensive evaluation of climate adaptation plans for a focus on equitable, climate-resilient water and sanitation.
- Research on the effectiveness of climate-resilience tools and frameworks from nonprofit and government agencies.
- An evaluation of the outcomes from programs designed to connect homes with decentralized, onsite water or sanitation systems that are at risk of failure due to climate change to centralized systems.
- Quantification and understanding of the types and distributions of benefits achieved from consolidation of water systems, recognizing they are likely case and context dependent. How effective are physical consolidations for increasing climate resilience and creating equitable outcomes for frontline communities?
- Identify O&M activities of both centralized and decentralized water and wastewater systems that help prepare for and prevent disruption or destruction of these systems from climate events.
- How are technologies for commercial, agricultural, and industrial water users affecting climate-resilience and equity for frontline communities? Furthermore, guidance is needed for the equitable implementation of climate-resilient water and sanitation technologies in these sectors.
- Research on the intersection of utility financial capability, household affordability, and climate resilience. There is an especially significant dearth of guidance relevant for small, underserved utilities and communities on this topic.
- Research on the equity and climate-resilience outcomes of monitoring and evaluating climate plans, especially related to water and sanitation.

- There are examples of frontline communities that have been able to obtain climate resilience funding for water and sanitation, but very little documentation of how they overcame the myriad barriers to obtaining and using that funding.
- The Bipartisan Infrastructure Law allowed for additional subsidization up to 49% using State Revolving Funds (SRFs). Has this resulted in additional SRFs being distributed as grants?
- Are there more states like Washington that are issuing protections for water access for households unable to afford their water bills during climate events?

The solutions to achieving equitable, climate-resilient water and sanitation in the US will always be place-based and context-dependent, so there is no one-size-fits-all. We hope that the examples, lessons learned, and tools reviewed in this report can support advancement toward this goal in many different locations, but this will require careful consideration of how to adapt strategies and approaches from one place to another. More work is needed to better understand and support the needs of and opportunities for frontline communities to build and maintain climate-resilient water and sanitation systems. Until those needs and opportunities are at the center of efforts to adapt and transform water and sanitation in the face of climate change, the solutions will fall short of achieving the goal of equitable, climate-resilient water and sanitation. We present this report as a knowledge foundation upon which to build practical solutions for the communities who need them the most.

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1. Preface

As climate change intensifies and accelerates, frontline communities will experience many of its changes and impacts through water. Droughts are becoming longer, hotter, and more frequent, leading to water supply shortages for homes, businesses, and ecosystems and creating conditions for more intense wildfires. Flooding from extreme storms and more intense precipitation events are damaging and destroying water and wastewater infrastructure, taking services offline for hours, days, weeks, or longer. Other events that are worsening under climate change, like wildfires and sea level rise, can wreak havoc on water quality, leaving homes and communities without access to safe drinking water. For frontline communities that are impacted first and worst, devastating climate events can lead to backsliding, i.e., loss of access to safe drinking water or a functioning sanitation system, either temporarily or permanently.

This report is the third in the *Water, Sanitation, and Climate Change in the United States* Series. This series aims to synthesize the state of knowledge and identify gaps at the intersection of climate change, water, and equity in the US. While these topics have received substantial attention individually, more work is needed to elucidate how and where they intersect.

In the first report of the series, *Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States*, we reviewed the literature on the effects of six climate change phenomena on water resources and water and sanitation in the US — extreme temperatures, drought, flooding, sea level rise, storms, and wildfires, especially for frontline communities. The report described the myriad ways in which each of the six climate change phenomena pose an immediate and future threat to water resources, water and sanitation systems, and water access for frontline communities.

In Part 2, titled *Law and Policies that Address Equitable, Climate-resilient Water and Sanitation,* we examined how the laws and policies that govern and inform water and sanitation service provision and infrastructure in the US address the impacts of climate change. Our research determined that most US water laws and policies were developed assuming historical climate trends that determine water availability would be constant and community vulnerability to climate would be the same over time. The research outlined how laws and policies often do not anticipate or help to proactively manage the impacts of climate change on water and wastewater systems in frontline communities. The report also underscored that existing US laws and policies, except in five states, do not recognize water and sanitation as human rights, threatening to widen the water access gap.

In this third report in the series, we highlight documented strategies and approaches for achieving equitable, climate-resilient water and sanitation in the US. Using an eight-part framework, we identify the attributes needed to achieve this goal, including why it is important and barriers to achieving it. We also provide examples of strategies and approaches for achieving this goal, with a focus on frontline communities in the US. The strategies outlined in this report are expected to remain relevant over time, though some are more time-bound and may not be available in the future.[3] This is particularly relevant for funding and financing mechanisms, which are likely to shift at the federal level with political and administrative changes. Notably, the research and writing for this report was completed in 2024. However, as we are preparing the document for publication in January 2025, some federal resources and funding mechanisms herein became unavailable following the White House administration change. Wherever possible, archived versions of websites and documents have been provided, although additional resources may become unavailable after this report is published. Ultimately, this report aims to demonstrate the broad array of tangible actions that are possible, and in many cases, are already being taken to achieve equitable, climate-resilient water and sanitation in the US, hopefully inspiring more action.

3 The report reflects strategies available as of January 2025.

2. Introduction

As climate change causes more frequent extreme storms and catastrophic floods, raises sea level, intensifies heat waves and droughts, and sparks more intense wildfires, frontline communities in the US will be at greater risk of losing access to safe, reliable drinking water and functional plumbing (Pacific Institute and DigDeep 2024). Already, more than 2 million people in the US live in the water access gap without running water and basic plumbing in their homes, and millions more are served by water systems with Safe Drinking Water Act violations (Roller et al. 2019). For these households and communities, climate change poses a more immediate threat in that they may not have the resources to prepare or defend their homes from wildfire; drought is drying up the streams, springs, and other sources they use for drinking and cooking; or, in an instant, floods can wash away the roads they rely on to reach a water filling station. However, frontline communities are resilient, and they are finding ways to overcome the myriad barriers and challenges they face from climate change to create equitable, climate-resilient water and sanitation access and systems.

In this report, we define frontline communities as those who are overburdened and underresourced and who face the disproportionate first and worst impacts of climate change on access to water and sanitation. Many frontline communities are found in "hotspots of plumbing poverty," i.e., clusters of households that suffer from limited to no access to water and sanitation services (Deitz and Meehan 2019). These hotspots stem from disputes over water rights and jurisdiction, inconsistent regulations, lack of investment in infrastructure, racism and discrimination, and water scarcity because of climate change and overextraction for other human uses (Campbell-Ferrari et al. 2024; Conroy-Ben and Richard 2018; Cozzetto et al. 2013; Deitz and Meehan 2019).

Frontline communities are resilient, and they are finding ways to overcome the myriad barriers and challenges they face from climate change to create equitable, climate-resilient water and sanitation access and systems.

People of color are more likely to experience the effects of Safe Drinking Water Act and Clean Water Act noncompliance and associated regulatory burdens (Mueller and Gasteyer 2021; Fedinick, Taylor, and Roberts 2019). These disproportionate impacts perpetuate poverty and racial inequality and create barriers to community capacity building and climate resilience (Norton 2023). For example, numerous

Indigenous communities in the contiguous US and Alaska lack adequate water and sanitation access (Payton et al. 2023). The Indian Health Service (IHS) reported in 2019 that more than 400,000 American Indian and Alaska Native homes had deficient sanitation (Indian Health Service 2020).

Because inequitable access to water and sanitation in the US is often underestimated or completely unrecognized, appropriate policy interventions are rarely taken (Meehan, Jepson, et al. 2020). A lack of data on water safety, reliability, safe wastewater management, and affordability at regional, neighborhood, and household scales means that many disparities in water and sanitation access go unnoticed by policymakers (Brown et al. 2023; Meehan, Jepson, et al. 2020). Further, the voices and needs of communities affected by the disparities are often overlooked, dismissed, or unmet which can result in mistrust between communities and service providers (Apul et al. 2021; Brown et al. 2023). Distrust of outside entities or those in positions of authority and power can further diminish capacity-building efforts as relationships and trust are essential to meaningful collaboration and decision making.

While national data on household access to drinking water and sanitation are incomplete, work by DigDeep (Roller et al. 2019) and other researchers (Deitz and Meehan 2019; Meehan, Jurjevich, et al. 2020; Mueller and Gasteyer 2021) has identified hotspots with either a high number or large proportion of unplumbed households or households with water that is unsafe to drink. Meehan and co-authors found that most unplumbed households in the US were in cities, and that these households were more likely to be renters, households of color, and people living in areas of growing income inequality (Meehan, Jurjevich, et al. 2020). Since the 2008 housing crisis, the lack of household access to running water has spread to more US cities, disproportionately affecting households of color and linking "plumbing poverty" to the broader issue of inadequate access to safe, affordable housing (Meehan et al. 2024).

> Human and economic development, public health, and quality of life are supported by clean, accessible, and affordable drinking water and sanitation services.

Human and economic development, public health, and quality of life are supported by clean, accessible, and affordable drinking water and sanitation services (Brown et al. 2023; Cutler and Miller 2004). Research by Mueller and Gasteyer found that incomplete plumbing correlates with "age, income, poverty, indigeneity, education, and rurality" (Mueller and Gasteyer 2021). In the US, 5.8% of Native American households lack complete plumbing and are 19 times more likely than White households to lack indoor plumbing (Roller et al. 2019). The lack of water and sanitation access is, thus, an issue of environmental injustice and an indication of the failure to secure a basic human right (Gleick 1998; Mueller and Gasteyer 2021).

Ensuring the human right to water and sanitation includes preparing for climate change, as discussed in the first and second reports in this series. To achieve the human right to water and sanitation, five essential components of water and sanitation services must be met — water and sanitation access must be sufficient, safe, acceptable, physically accessible, and affordable (California Environmental Protection Agency 2021a; United Nations 2014). Yet climate change is already making it more difficult to meet these requirements.

Achieving the human right to water and sanitation by ensuring sufficient, safe, acceptable, physically accessible, and affordable water and sanitation for all people in the US will be no small task, even without the ongoing and growing impacts of climate change. However, without the reduction of climate-altering greenhouse gases by major economies around the globe, the impacts of climate change will dramatically worsen in the coming decades and persist for generations to come (Canadell et al. 2021). Even with dramatic reductions in greenhouse gas emissions, current increases in global average temperatures from historical emissions mean that changes such as sea level rise, more severe storms, extreme temperatures, and intensified droughts will continue for decades to come (Jay et al. 2023).

Communities already experiencing tenuous, incomplete, or nonexistent water and sanitation access are most at risk because they start from a point of greater disadvantage. Households that already collect and haul water outside the home, which is physically taxing, time intensive, and often expensive, are particularly vulnerable (DigDeep 2022). For example, approximately 30% of Navajo Nation households lack running water and rely on hauled water to meet their basic daily needs (Navajo Nation Department of Water Resources 2003). Increased stress from a changing climate will further challenge these communities by increasing the number of days with extreme heat, heightening the risk of wildfires, intensifying storms, contaminating surface supplies and groundwater sources they depend on, and more.

When these households can finally install water and sanitation systems or connect to centralized services, it is imperative that their access is resilient to ongoing climate shocks and stresses to prevent backsliding. Backsliding is described by DigDeep and US Water Alliance as the concerning increase in the number of homes without water or sanitation access (Roller et al. 2019). Here backsliding refers to the process by which a climate phenomenon causes a home or a community to lose access to water sanitation, either temporarily or permanently. In the first report in this series, we identified and discussed six types of climate change phenomena that impact water and sanitation systems and water resources and can cause a loss of access and backsliding for frontline communities.

> This report aims to identify documented strategies and approaches for achieving equitable, climate-resilient water and sanitation for frontline communities in the US.

Despite barriers and challenges to equitable, climate-resilient water and sanitation access and systems in the US, frontline communities and their supporters all over the country are making strides toward water access. This report aims to identify documented strategies and approaches for achieving equitable, climate-resilient water and sanitation for frontline communities in the US. To do this, we first answer the question: What are the attributes of equitable, climate-resilient water and sanitation? We developed a framework to organize, categorize, and communicate these attributes and identify some documented strategies and approaches and associated barriers and challenges. The rest of the report is structured as follows:

- Section 3 presents the organizing framework with the categories and attributes of equitable, climate-resilient water and sanitation for frontline communities and how we used this framework to identify strategies and approaches for achieving this goal.
- Sections 4 through 10 are organized around each category, or type, and each category includes multiple attributes. For each attribute we describe the attribute, including why it is important for achieving equitable, climate-resilient water and sanitation; the barriers and challenges to achieving it; and some strategies and approaches for achieving it. Case examples throughout these sections help ground the discussions, including three place-based stories from interviews conducted by DigDeep with individuals and communities. These stories highlight successful efforts to advance climate-resilient water and sanitation in the Navajo Nation (Section 5.5), Appalachia (Section 8.6), and colonias along the US-Mexico border (Section 10.5).
- Section 11 is the conclusion and includes a summary of the strategies and approaches we identified, as well as research, knowledge gaps, and recommendations for future research. The strategies cover a range of actors and sectors within frontline communities, including but not limited to water and sanitation managers, communities and community-based organizations, other nonprofits, and policymakers.

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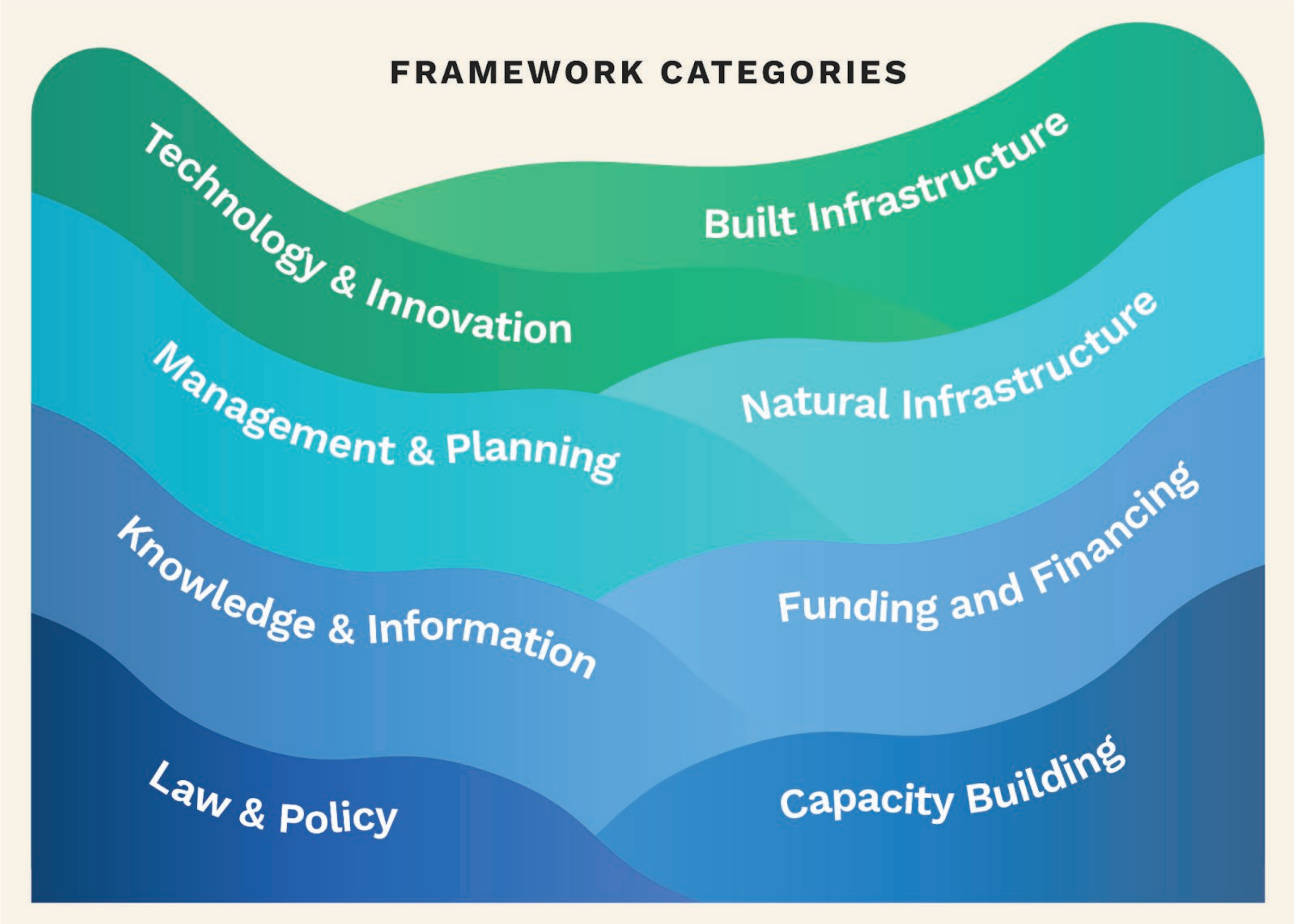
3. A Framework for Achieving Equitable, Climate-Resilient Water and Sanitation

To identify strategies and approaches for achieving equitable, climate-resilient water and sanitation, we developed a literature-informed framework to categorize and communicate the broad set of components required for this goal (Figure 1). The framework is composed of eight categories or types of attributes that address barriers for achieving equitable, climate-resilient water and sanitation in the US. These include built infrastructure, technology and innovation, natural infrastructure, management and planning, funding and financing, knowledge and information, capacity building, and law and policy.[4]

4 The law and policy attributes will be addressed in a forthcoming report in 2025 and are not included in Table ES1.

FIGURE 1. Framework for Achieving Equitable, Climate-Resilient Water and Sanitation



Note: The figure depicts the eight categories of climate-resilient and equitable water and sanitation, which serves as the organizing framework for the attributes and corresponding strategies in the report. The visualization incorporates themes and colors from the Pacific Institute's logo, using wave imagery to emphasize the eight framework categories and their interconnections in building equitable, climate-resilient water and sanitation systems.

Figure designed by Pacific Institute and DigDeep, graphic design by Max Olson, DigDeep

We sought to identify documented attributes, barriers or challenges, and strategies or approaches related to achieving equitable, climate-resilient water and sanitation for frontline communities in the US. To develop the framework and attributes, we reviewed academic literature, government and NGO reports, and online tools. In addition, we solicited input from practitioners at conferences and through online meetings and discussions. We primarily focused on literature, resources, and case examples from the US but drew on literature from non-US contexts when relevant.

During our initial review, we identified 120 attributes (i.e., ideal characteristics, goals, or outcomes) of equitable, climate-resilient water and sanitation. We combined these into 31 attributes, which we organized into the eight major categories (Figure 1).[5] While the framework includes law and policy attributes, this report does not include a section on the strategies and approaches for the law and policy attributes. We will address this category in a future report that focuses on the law and policy attributes.

Although extensive, this assessment is likely incomplete due to gaps in available data and documented information. Furthermore, we do not address climate change mitigation strategies and approaches to reduce greenhouse gas emissions. More work is needed to refine this framework and fill research gaps, which we identify in the conclusion.

5 The number of attributes does not include the Law and Policy attributes, which will be finalized in the forthcoming report.

3.1 CHARACTERISTICS OF THE STRATEGIES AND APPROACHES TO EQUITABLE, CLIMATE-RESILIENT WATER AND SANITATION

We have identified and synthesized a diverse set of documented strategies and approaches developed for frontline communities, their supporters (e.g., community-based organizations or nonprofits), water resource managers, water and wastewater utilities, policy and law makers, and Tribal, federal, state, and local governments, to advance equitable, climate-resilient water and sanitation in the US. The strategies presented here serve as examples of what can be achieved, not as one-size-fits-all solutions. These strategies and approaches encompass various forms, ranging from frameworks and activities to legal and policy efforts and programs to technologies and data.

Several key characteristics define the strategies and approaches presented. First, we prioritize solutions that are salient, credible, and well-grounded in the specific contexts where they are implemented (Cash et al. 2003). Because of this, most of these strategies and approaches are highly contextual and need to be carefully adapted to different communities based on their unique needs and contexts. Whenever possible, we include context to help our readers consider whether or how a similar approach might work in their community.

Second, not all examples demonstrate complete feasibility or success, often because they have not been fully implemented, monitored, and evaluated, or we simply were unable to find documentation on outcomes. Yet valuable lessons can be gleaned, even from approaches that have not achieved full success. Many such initiatives represent steps in the right direction, contributing to progress and incremental change.

Lastly, it’s essential to recognize that approaches inherently vary based on the role and agency of the person or group applying them, considering factors like type, scale, and geography. Here we focus on identifying and exploring approaches that are most relevant for:

- Community-based organizations and implementers in frontline communities;
- Water and sanitation managers and agencies, including utilities; and
- Decision makers at the Tribal, federal, state, and local levels.

We did not do a comprehensive review of all of the examples of strategies and approaches across the nation. Instead, we sought to include examples from a diverse set of geographies, communities, and water and sanitation system types (i.e., centralized and decentralized). As stated, many of these strategies and approaches will only work when thoughtfully tailored for the context in which they will be implemented and in close partnership with the communities they are meant to serve.

4. Built Infrastructure

This category of attributes describes new or improved built infrastructure aimed at providing equitable, climate-resilient water and sanitation for frontline communities.

Built infrastructure that supplies clean, safe drinking water and removes, treats, and restores treated wastewater back to the environment is critical for equitable, climate-resilient water and sanitation. Here, built water and sanitation infrastructure refers to the pumps, pipes, reservoirs, wells, treatment plants, sewer lines, etc., that are constructed and maintained by centralized drinking water and wastewater systems, as well as domestic wells and septic systems constructed and maintained by households for onsite water and sanitation. The appliances and fixtures that end users typically interact with in their home, such as toilets, sinks, air conditioners, or dishwashers are addressed in Technology and Innovation (Section 5). Infrastructure that incorporates nature or natural processes to help supply and provide clean, safe drinking water or remove and treat wastewater (i.e., nature-based solutions and green infrastructure) is addressed in Section 6, Natural Infrastructure.

Unfortunately, water and sanitation infrastructure and services have not been equitably provided to all households in the US (Roller et al. 2019). Furthermore, in *Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States*, we described how the existing infrastructure in frontline communities is at high risk for climate disruptions and damages with few resources to adapt to or recover from increasing impacts of climate change (Pacific Institute and DigDeep 2024). These climate impacts include:

- Damage to treatment and distribution systems caused by flooding (among the costliest types of natural disaster in the US);
- Melting of pipes, wells, water meters, and other equipment during wildfires;
- Submersion of wastewater outfall pipes along coastlines due to sea level rise;
- Extreme heat and drought causing well failures, particularly for shallow wells; and
- Etreme cold events leading to ruptured water pipes, power outages, and septic system failure (Pacific Institute and DigDeep 2024; Taylor et al. 2024; Calabretta, Cunningham, and Vedachalam 2022).

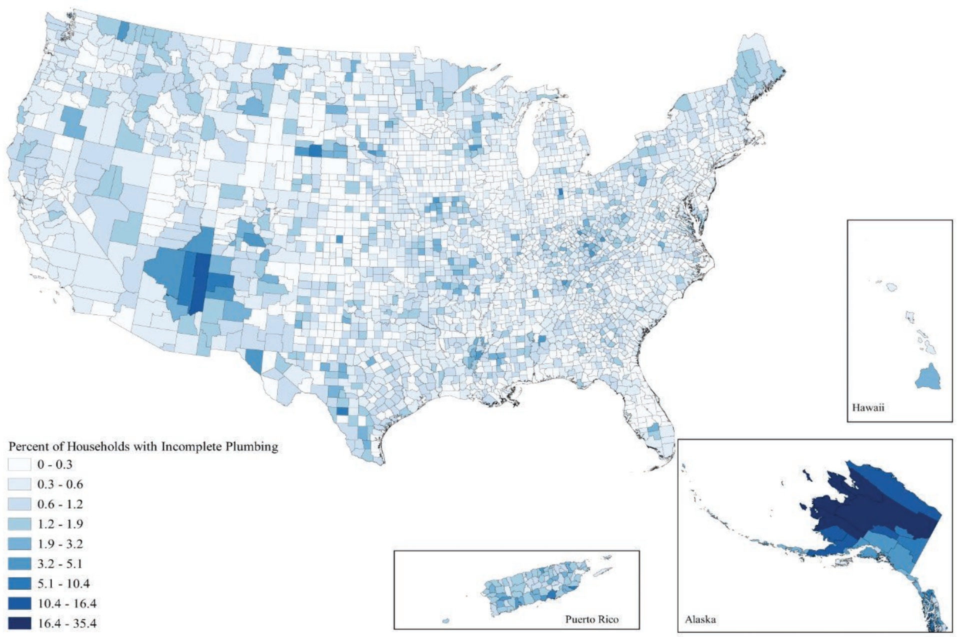
There are four attributes of built infrastructure needed for equitable and climate-resilient water and sanitation. These include the presence of built water and sanitation infrastructure to ensure universal access; reliable infrastructure performance under a wide range of conditions; inclusive and equitable processes for siting, designing, and constructing climate-resilient water and sanitation infrastructure; and equitable, climate-resilient O&M of infrastructure.

4.1. ACCESS TO WATER AND SANITATION INFRASTRUCTURE AND SERVICES

Attribute description: Frontline communities have access to drinking water and sanitation infrastructure and services that allow them to perform basic everyday tasks and personal hygiene in their homes.

Access to safe, affordable water and sanitation is necessary for people and communities to be resilient to climate change. Yet in the US, frontline communities are more commonly located in "hotspots of plumbing poverty" where households that suffer from limited to no water access and sanitation services are clustered (Deitz and Meehan 2019). These communities lack full indoor plumbing and are also more likely to be served by community water systems in violation of the Safe Drinking Water Act or Clean Water Act (Mueller and Gasteyer 2021) (Figure 2 and 3). While many of these households are rural, Meehan and co-authors (2020a) found that 73% of households that lack a piped water connection are in cities. Several regional hotspots of water and sanitation access gaps include California's Central Valley, the Navajo Nation, rural Alaska, colonias[6] along the border with Mexico, the Deep South, Appalachia, the Northeast, and Puerto Rico (Deitz and Meehan 2019; Mueller and Gasteyer 2021; Roller et al. 2019). There is evidence that these hotspots correspond with higher rates of poverty, non-White populations, and Tribal or Indigenous communities (Deitz and Meehan 2019; Mueller and Gasteyer 2021). According to the Fifth US National Climate Assessment, these communities are disproportionately affected by environmental hazards and climate change (Marino et al. 2023).

FIGURE 2. Map of the Percent of County Households without full Plumbing as Reported by the 2014–2018 American Community Survey

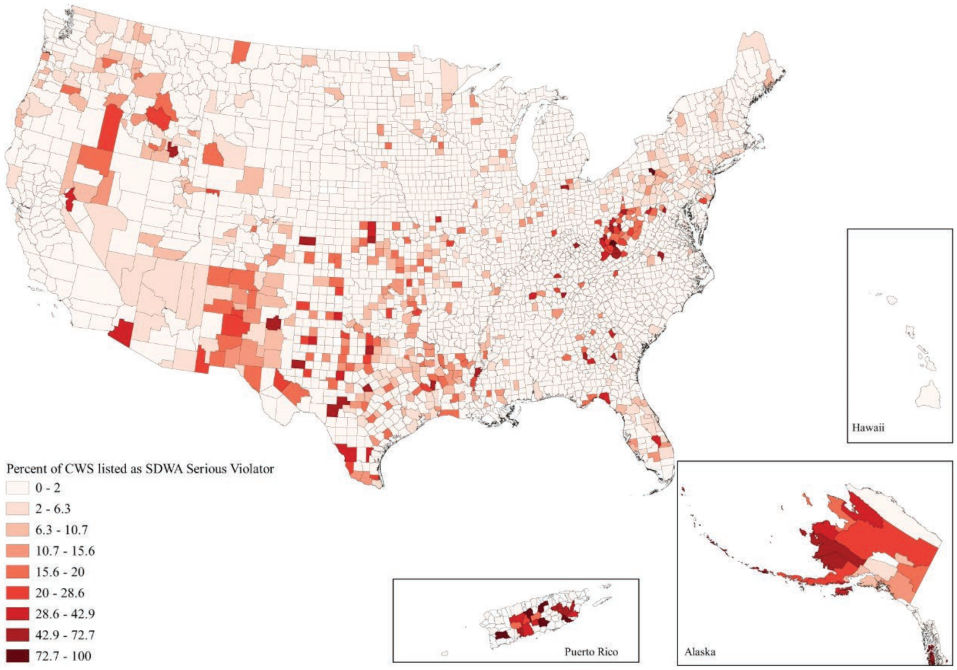


Note: Households have incomplete plumbing if they do not have access to hot and cold water, a sink with a faucet, and a bath or shower. Prior to 2016, a flush toilet was also included in the definition of incomplete plumbing.

Source: Mueller and Gasteyer 2021

6 *Colonias* are unincorporated communities in the Southwestern US along the US-Mexico border.

FIGURE 3. Map of the Percent of Active County Community Water Systems Listed as Safe Drinking Water Act (SDWA) Serious Violators



Note: Safe Drinking Water Act Serious Violators are those community water systems regarded by the EPA as the most problematic due to violation and compliance history.

Source: Mueller and Gasteyer 2021

One reason why frontline communities lack adequate water and wastewater infrastructure is the persistence of "myths" about access in high-income countries like the US (Meehan, Jepson, et al. 2020). Meehan and co-authors succinctly summarized these myths, which include the belief that water and sanitation access is already "universal, clean, affordable, trustworthy, and uniformly or equitably governed" in the US. These myths hide long-standing inequities in high-income countries, inhibiting policy and progress toward universal infrastructure coverage and other foundational components to equitable, climate-resilient water and sanitation access.

Racist policies and practices, such as redlining[7] (Bailey, Feldman, and Bassett 2021), restrictive racial covenants, and underbounding[8] (Braveman et al. 2022; Brown et al. 2023; Leker and Gibson 2018) are also key barriers to equitable water and sanitation infrastructure. For example, Sterling (2022) found that across 202 cities in the US, an average of 15% households in redlined areas lacked

7 Redlining refers to the discriminatory historical practice of labeling neighborhoods — typically predominantly Black neighborhoods — as unsuitable for home loans and other services. This left a legacy of inequitable government service outcomes, including for water and wastewater (Braveman et al. 2022).

8 The term *underbounding* describes the exclusion of certain homes and communities from a municipal boundary and associated services. Underbounding is a form of political exclusion that occurs when Black or other marginalized communities "are kept just outside of a town's boundaries, resulting in lower levels of services, reduced access to infrastructure, and limited or no political voice in land-use or permitting decisions" (Parnell 2004). Peri-urban areas are areas on the periphery of urban centers, at the interface between rural and urban communities, that can lack services and infrastructure afforded to communities within the urban core (Gottero, Larcher, and Cassatella 2023).

complete plumbing, as compared to only 5.3% households in greenlined neighborhoods.[9] Leker and Gibson (2018) showed evidence that under bounding in peri-urban areas in North Carolina led to lack of centralized water and sewer system access and that it is more likely for low-income Black populations. Due to disinvestment and lack of services, these communities are often at higher risk of impacts from extreme events like heat waves, inland flooding, and wildfires (Chang et al. 2023; Linscott et al. 2022).

Tribal and Indigenous communities have some of the worst access to water and sanitation in the US. Data from the US Census show that American Indian and Alaska Native (AI/AN) populations are 19 times more likely to lack complete plumbing in their homes than White households (Roller et al. 2019). Figure 4 shows data from the IHS database of AI/AN homes requiring sanitation facility improvements within their service areas. In the most recent annual report to US Congress for Fiscal Year 2022 (FY), the IHS reported that nearly 114,000 (30%) AI/AN homes required improvements in order to meet adequate sanitation levels (Indian Health Service 2022). Approximately 5,900 AI/AN homes (1.6%) were reported to lack safe water supply and a sanitation system (Indian Health Service 2022). The Status of Tribes and Climate Change Report stated that IHS likely underestimates AI/AN homes that lack adequate water and sanitation (Status of Tribes and Climate Change Working Group 2021). Lack of water and sanitation puts these households and their communities at even greater risk from climate change impacts, as water insecurity for Tribal and Indigenous communities may cause food insecurity and impede traditional farming and other cultural practices (Status of Tribes and Climate Change Working Group 2021).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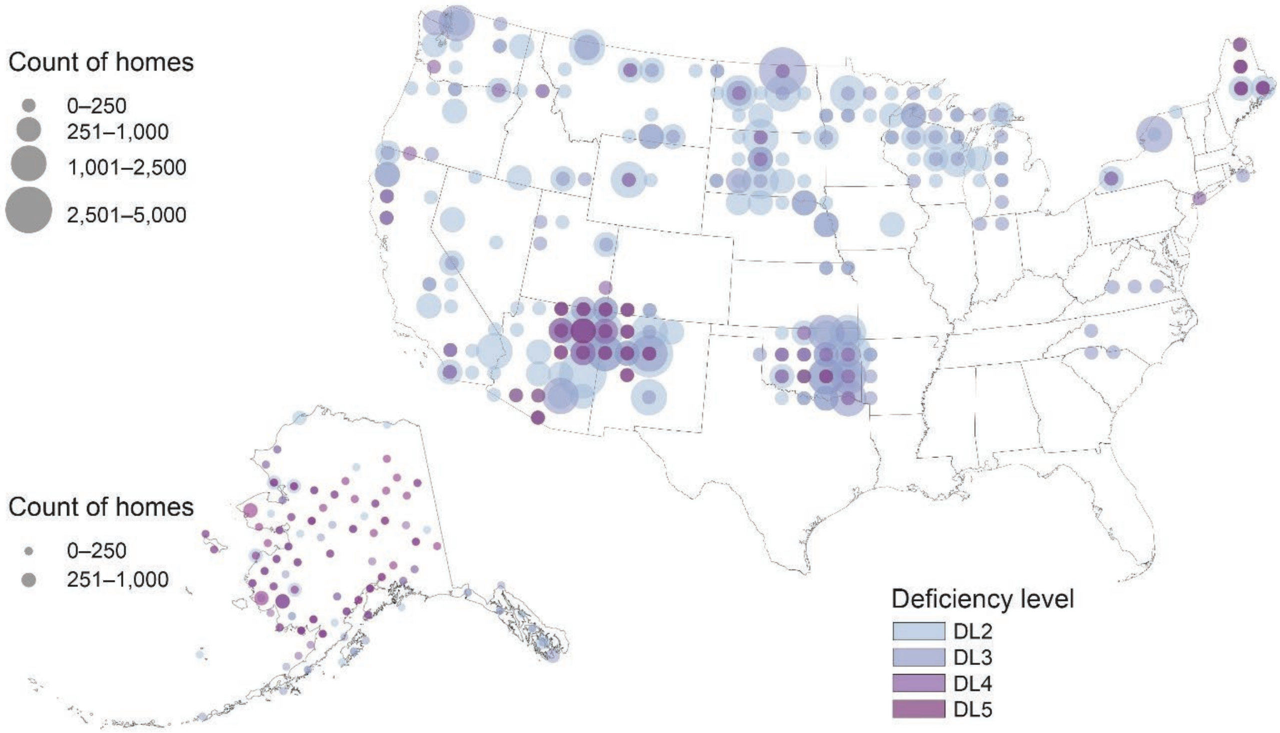
9 Greenlined neighborhoods, in contrast to redlined neighborhoods, were labeled as suitable for home loans and other services and were predominately home to White populations.

FIGURE 4. American Indian and Alaska Native Homes Requiring Water and Sewer System Improvements



Note: The map reports the number of American Indian and Alaska Native households with a plumbing deficiency level (DL) ranging from level 2 (capital improvements are necessary to meet domestic sanitation needs) to level 5 (lacks a safe water supply and a sewage disposal system).

Source: Payton et al. 2023

The barriers to addressing the needs for Tribal and Indigenous water and sanitation infrastructure in the US overlap with, but also go beyond, what many other non-Tribal communities with insufficient infrastructure experience. Barriers for Tribes may include: challenges obtaining rights of way, fractionation and fragmentation of land ownership, lack of eminent domain authority, conflicting regulations concerning Tribal preference in hiring and awarding contracts, partial waiver of sovereign immunity, dispute resolution challenges, lack of planning, legacy of inadequate environmental enforcement, lack of Tribal authority to create water districts, and lack of operator certification requirements (Doyle et al. 2018). Climate change is a risk multiplier that exacerbates many of these challenges for Tribes. McNeeley (2017) discussed the structural barriers to climate adaptation of water resources, which resulted from the legacy of US Federal government removal, allotment, and homestead polices from the 1800s and early 1900s. McNeeley demonstrated that, at the Wind River Reservation in Wyoming, while some of these federal policies and practices have changed, structural inequities endure and limit the ability of local Tribes to sustainably manage water resources and adapt to climate change.

Despite these challenges, some progress is being made to bring climate-resilient water and sanitation to frontline communities in the US. In the Navajo Nation, where approximately 30% of homes still lack running water (Navajo Nation Department of Water Resources 2003), a community partnership with DigDeep has helped to advance the Navajo Water Project (see Herbert's Story in

Section 5.5). Indigenous-led and registered as an official enterprise on the Navajo Nation, the project installs decentralized, onsite water and wastewater systems; repairs and replaces failing septic systems; supports community-based job training; and offers grants to individuals and communities for addressing their own water challenges. As of 2024, the project has installed over 750 home water systems, directly impacting more than 2,000 individuals. In the case study from the Navajo Nation, we provide a glimpse of how the project has incorporated off-grid, onsite water and sanitation systems to improve climate resilience in the face of increasing water scarcity and risk and drought in the region.

Alaska is another place that is working to build equitable, climate-resilient infrastructure. Most Alaska Native villages are remote and on the frontlines of climate change that is causing widescale erosion, flooding, and permafrost thaw, damaging infrastructure (Alaska Native Tribal Health Consortium 2024; Huntington et al. 2023). At least 144 Alaska Native communities face threats to their infrastructure from natural hazards caused by climate change (Alaska Native Tribal Health Consortium 2024). The Alaska Native Tribal Health Consortium, a nonprofit Tribal health organization designed to meet the unique health needs of Alaska Native and American Indian people living in Alaska, supports construction of water and sanitation facilities in remote Alaska. To improve the health of Alaska Native people, one of the programs they offer installs wells, cisterns, and septic systems for individual homes and communities. However, some Alaska Native communities require temporary, mobile solutions due to forced relocation from diminishing sea ice, increasing storms, and tidal surges (Alaska Native Tribal Health Consortium 2017).

In many frontline communities, adaptation of existing infrastructure may help to improve climate resilience and prevent backsliding. Communities reliant on septic systems along the coast are uniquely at risk from rising water tables due to sea level rise. Along the Southeastern Florida coast, sea level rise has already been measured at 3.9 inches from 2000 to 2017 (Southeast Florida Regional Climate Change Compact's Sea Level Rise Ad Hoc Work Group 2019). In Miami-Dade County, Florida, there were approximately 120,000 septic systems in use, of which approximately 9,000 were vulnerable to compromise or failure based on groundwater conditions (Miami-Dade County and Florida Department of Health 2018). By 2040, that number is expected to rise to 13,500 (Miami-Dade County and Florida Department of Health 2018). This county created a program, Connect-to-Protect, to connect at-risk households to more climate-robust centralized wastewater services (Miami-Dade County 2023). However, it is not clear what costs of connection will be borne by the household versus the wastewater system, nor whether funding will be prioritized for low-income households.

> Despite the barriers and challenges, work is underway to close the water and sanitation access gap, helping to secure a foundational component of climate resilience for frontline communities.

In the US, water and sanitation infrastructure and services do not exist for everyone. Contrary to persistent myths that everyone in the US has clean, safe, affordable water, due to racist legacies and institutions and other structural barriers, more than 2 million people in the US lack running water and basic plumbing (Roller et al. 2019). These communities are being forced to face climate change without the ability to cool off with water from a sink or shower, to stay adequately hydrated, or to protect their homes from wildfires. Despite the barriers and challenges, work is underway to close the water and sanitation access gap, helping to secure a foundational component of climate resilience for frontline communities. Some of the strategies to close the water and sanitation access gap in the US are:

1. **Initiate and support community-led water and sanitation infrastructure projects with nonprofit organizations and other entities dedicated to closing the water and sanitation access gap; and**
2. **Create local programs to connect households and communities with water and sanitation systems at risk from climate impacts to more climate-robust centralized water and/or sanitation systems.**

Through community-led initiatives to expand water and sanitation infrastructure to those currently lacking and local programs to reduce the risk of backsliding from climate impacts, frontline communities will be better able to withstand growing risks from climate change.

4.2 BUILT INFRASTRUCTURE PERFORMING RELIABLY UNDER A RANGE OF CLIMATE CHANGE IMPACTS

Attribute description: Built infrastructure performs reliably under a wide range of climatic conditions, delivering safe, sufficient, and acceptable water and sanitation for frontline communities.

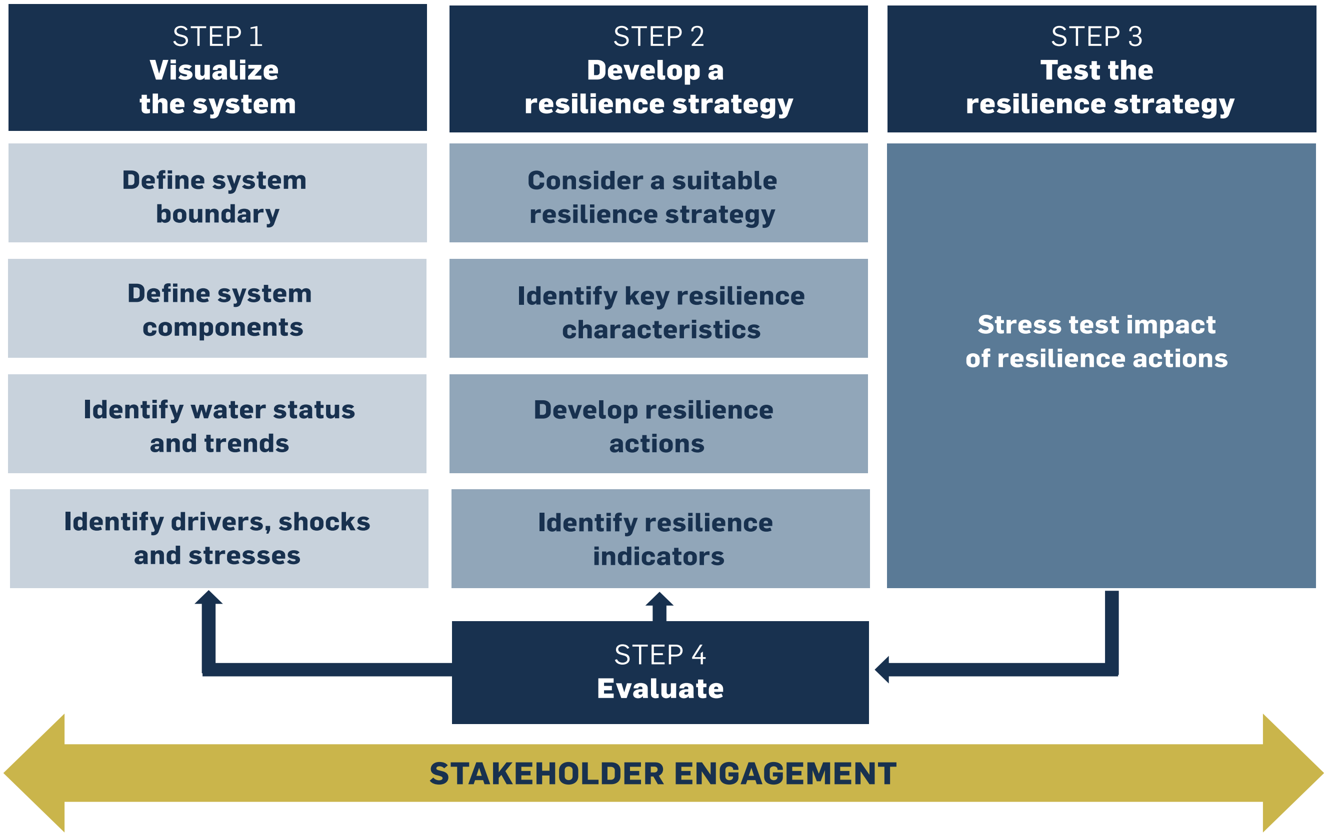
Most of the drinking and wastewater infrastructure in the US was built using estimates for operation and performance based on historical climate trends with an assumption of "stationarity" (Milly et al. 2008). This means they were constructed assuming a stationary climate where the frequency and severity of climate impacts do not change over time (Cheng and AghaKouchak 2014; Lall et al. 2018). However, it is now increasingly recognized that climate change means the past trends cannot necessarily help predict the future (Marvel et al. 2023; Payton et al. 2023). For equitable, climate-resilient water and sanitation, built infrastructure will need to be designed to perform reliably under a wider range of climatic conditions, so that it can deliver safe, sufficient, and acceptable water and sanitation to frontline communities.

In 2021, the American Society of Civil Engineers issued "report cards" for the condition and investment of infrastructure in the US. The US drinking water infrastructure received a C- due to its aging condition, regular failures, and lack of investment; dams, wastewater infrastructure, stormwater infrastructure, and levees all received D grades (American Society of Civil Engineers 2021b; 2021c; 2021d; 2021e; 2021f). While not directly a measurement of reliability under a range of climatic conditions, these scores indicate that water and sanitation infrastructure in the US is already in a general state of disrepair. Similarly, both the Fourth and Fifth US National Climate Assessments highlighted the need for adaptation of the Nation's deteriorating water infrastructure (Lall et al. 2018; Payton et al. 2023). Notably, little is known about the reliability or condition of water and sanitation systems that serve single households, like domestic wells and septic tanks, yet these decentralized systems need to be able to perform reliably and effectively under a range of stressors and shocks as well (Pacific Institute and DigDeep 2024).

Climate change is drastically altering the water cycle and other natural phenomena in ways that will challenge the water infrastructure of frontline communities to perform reliably (Pacific Institute and DigDeep 2024). As such, those who are responsible for operating and maintaining water and sanitation infrastructure need ways to assess infrastructure reliability under a range of climatic conditions. Several tools and frameworks for evaluating the climate resilience of water infrastructure have been developed, including:

- "How tough is WASH framework" by Howard et al. (2021). In this simple framework for assessing resilience of water and sanitation systems and access, there are six "domains" of resilience: infrastructure, environmental setting, water and sanitation management, supply chains, community governance and engagement, and institutional support, with a focus on floods and droughts. Each domain has an assessment method and scale. For infrastructure, the method was described as "assessment of sanitary integrity and protection, water quality, and yield analysis" at the scale of the individual water supply or sanitation system. There is a Likert scale for each domain ranging from 1 (very low resilience) to 5 (very high resilience). The scores indicated the likelihood that the water supply or sanitation system could cope with climatic events and prevent adverse impacts. The framework was developed particularly for rural communities and small towns in low- and middle-income countries and may therefore be relevant to and practical for resource- and capacity-constrained frontline communities in the US (Howard et al. 2021).
- The US EPA's Vulnerability Self-Assessment Tool (VSAT) that water and wastewater systems can use to assess risk and resilience of their assets (US EPA, OW 2015e). This tool was made for utilities of all sizes to help identify the highest risks, including climate risks, to their "mission-critical operations" and measures to reduce those risks that are cost-effective. VSAT was designed to work on mobile devices as well as computers.
- The US EPA's Climate Resilience Evaluation and Awareness Tool (CREAT) was developed to assist water utilities in assessing climate-related risks to their infrastructure and operations (US EPA 2014a). The tool has five modules to help utilities consider climate impacts and identify adaptation options: 1) climate awareness, 2) scenario development, 3) consequences and assets, 4) adaptation planning, and 5) risk assessment. CREAT can import results from VSAT.
- The Water Resilience Assessment Framework (WRAF), by CEO Water Mandate, Pacific Institute, the Alliance for Global Water Adaptation, the International Water Management Institute, and World Resources Institute, was developed to allow practitioners to create common measurable goals and outcomes for stakeholder and resilience planning. The WRAF consists of four key steps: visualizing the system, developing a resilience strategy, testing the resilience strategy, and evaluating (Figure 5). Three guidance documents have been developed to help basin water managers, utilities, and corporations apply the WRAF (CEO Water Mandate 2024).

FIGURE 5. The Water Resilience Assessment Framework



Source: Chapagain et al. 2021

We see an increasing number of documented approaches to water and sanitation infrastructure adaptation in the US. Such strategies must be tailored to the places where they are being implemented, and they must be able to address a range of climate conditions, shocks, and stresses. For example, the Chickasaw Nation and Choctaw Nation of Oklahoma have led adaptation projects addressing climate impacts on their water supply, which is primarily the Arbuckle-Simpson Aquifer. These Nations have worked with communities affected by climate change to assess industrial and municipal wastewater reuse, test aquifer recharge, and find and fix water supply/distribution leaks. (Cozzetto, Cooley, and Taylor 2021). These actions are sought to ensure that water supplies are available to all communities in the region, even during times of drought.

Coastal wastewater systems, such as the treatment plants and underground pipes that return treated effluent to nearby waterways, are among the first systems directly impacted by sea level rise and extreme coastal storm events. In Massachusetts, planners as early as the 1980s began to incorporate climate projections into their local planning decisions, including updating a wastewater treatment plant in Boston Harbor (Gregg and Braddock 2021). Due to their early incorporation of climate projections, the wastewater plant was elevated by 1.9 feet, reducing the need for pumps to discharge wastewater as the sea level has risen.

The increasing occurrence and intensity of wildfires, especially in the Western US, have left many drinking water systems in need of infrastructure upgrades and climate adaptations. The Marshall

Fire that occurred in December of 2021 in Colorado was one such event. After an unusually wet spring, followed by very dry fall and winter, there was an excess of dry vegetation along the Front Range of Colorado. On December 30th high winds caused two grass fires to rapidly expand, engulfing over 1,000 homes and structures, damaging six public drinking water systems, and destroying over 200 private wells (Jankowski et al. 2023; Whelton et al. 2023). During recovery from the fire, water system engineers recommended updating drinking water distribution systems with backflow prevention devices on service lines, meters with the ability to automatically shut-off, and keeping plastic infrastructure away from heat sources (Whelton et al. 2023). Whelton et al. stated that these changes can help reduce the potential for damage, depressurization, and contamination in the event of wildfire in the direct service area.

> Water systems that rely on a single source are highly vulnerable to extreme weather and climate events because they lack backup options if their supplies become contaminated, unavailable from drought, or if they become physically disconnected due to damaged infrastructure.

Water systems that rely on a single source are highly vulnerable to extreme weather and climate events because they lack backup options if their supplies become contaminated, unavailable from drought (Mullin 2020), or if they become physically disconnected due to damaged infrastructure. Building a physical connection to another drinking water supply can help prevent disruptions from unexpected or extreme events (Dobbin, McBride, and Pierce 2023). Physical connections created between two or more water systems are referred to as a consolidation, because often the systems end up creating a shared governance structure that makes them a single water system. However, the governance structure created by a consolidation can vary and does not require full ownership transfer. The Rural Community Assistance Partnership (RCAP) considers consolidation a form of partnership between water or wastewater systems and has noted a spectrum of formality in governance or partnership approaches (Landes et al. 2020). Partnerships can range in formality from informal cooperation, to contractual assistance, to shared governance, to a complete ownership transfer (Landes et al. 2020). While many researchers and government agencies promote interconnections to address a wide range of technical, managerial, financial, and resilience challenges, communities have opposed them because of the perceived or real loss of local control (Dobbin, McBride, and Pierce 2023; Mullin 2020). RCAP's 2020 and 2021 reports, with policy recommendations and lessons learned on water and wastewater system partnerships (another term for interconnections), are useful for understanding key governance and equity considerations when pursuing different kinds of interconnection agreements (Landes et al. 2020; 2021).

Outcomes from interconnections have not been well studied, yet one analysis of consolidations of 206 California water systems between 2015 and 2021 found that most occurred among underperforming, climate-vulnerable systems, with a disproportionate number of these involving nonresidential water systems or systems serving high-income populations (Dobbin, McBride, and Pierce 2023). The study authors concluded that, at least in California, consolidation was not effectively targeting systems serving low-income communities or communities of color. Research by Mullin (2020) states that consolidation can reduce risks of drought and other unexpected events, although climate vulnerability post consolidation was not assessed.

There are myriad other ways that infrastructure can be made to adapt and build resilience to climate change, increasing reliability. These may include infrastructure retrofits to elevate low-lying coastal infrastructure, relocation of community water stations, deepening groundwater wells, or directing floodwaters to regions to enhance groundwater recharge (Alaska Native Tribal Health Consortium 2024; Hasert et al. 2024; Scanlon et al. 2016; Status of Tribes and Climate Change Working Group 2021). Two online resources with more examples of infrastructure adaptation are the US Climate Resilience Toolkit and Climate Adaptation Knowledge Exchange. Notably, there is very little known about the success of these changes in the face of climate impacts (Owen 2020), although efforts are underway to create metrics for evaluating water and sanitation resilience (e.g., Chapagain et al. 2021).

Evaluating the climate resilience of water and sanitation infrastructure requires new tools and metrics. Already, water and sanitation infrastructure is being adapted to new and future climate realities, such as by expanding industrial and municipal wastewater reuse facilities, elevating near-shore wastewater treatment plants, and consolidating two or more drinking water systems so they physically connect and support each other during times of drought. The strategies explored here for improving the reliability of water and sanitation infrastructure under a range of climate conditions are:

1. **Create tools and frameworks for water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure;**
2. **Improve water supply reliability through water reuse, fixing leaks in distribution systems, recharging aquifers (with floodwater where possible), and deepening groundwater wells;**
3. **Consider consolidation through a range of partnership forms to improve supply reliability during climate emergencies;**
4. **Elevate coastal infrastructure to protect it from sea level rise;**
5. **Adapt infrastructure to be better prepared for wildfire by adding backflow prevention devices on service lines, installing meters with the ability to automatically shut off, and keeping plastic infrastructure away from heat sources; and**
6. **When necessary, relocate community water stations and other infrastructure to protect them from damage and destruction.**

Ultimately, the strategy chosen must be based on site-specific factors as well as the direct needs and desires of the community being served. Once built, the ongoing O&M of these systems needs to incorporate equity and climate resilience to ensure that the systems continue to perform reliably over the long term.

4.3 INCLUSIVE AND CLIMATE-RESILIENT SITING, DESIGN, AND CONSTRUCTION

Attribute description: Processes for siting, designing, and constructing climate-resilient water and sanitation infrastructure are inclusive and equitable and ensure centering of frontline community values and needs.

The siting, design, and construction of water and wastewater infrastructure (such as treatment plants, supply pipelines, water towers, dams, and sewer lines) require careful consideration of multiple factors. Among these factors are technical specifications, regulatory requirements, costs, climate resilience, and impact on the hosting community. In addition, many infrastructure projects require a "social license to operate," which means that gaining acceptance and approval by the local community may be necessary; otherwise, a project may become socially and politically infeasible (Jijelava and Vanclay 2018). Here, we focus on the need for inclusive, equitable processes for siting, designing, and constructing climate-resilient infrastructure.

The negative impacts of water and sanitation infrastructure often focus on a specific location, while the benefits are commonly more geographically distributed. For example, a wastewater treatment plant that serves hundreds or thousands of homes and businesses must be placed in a single location, sometimes near a body of water like an ocean or river. Those living in the vicinity may be impacted daily by the operating noise, traffic, or odors from the sewage and wastewater. Also, people living near the outfall pipe from a wastewater treatment plant may regularly experience changes in water quality, smell, and appearance. If a plant experiences failures, such as during an extreme rainstorm that overwhelms the system causing an overflow event, those same communities may be exposed to untreated sewage in the water.[10]

Because climate change is expected to increase the frequency and severity of heavy precipitation events (defined as the total precipitation on the heaviest 1% of days) (Marvel et al. 2023), overflow events may become more frequent and severe as well. Along the Atlantic coast of the US in 2012, in the days and weeks after Hurricane Sandy 11 billion gallons of untreated and partially treated sewage flowed into rivers, bays, canals, and some city streets as a result of storm surge flooding to treatment plants (Kenward, Yawitz, and Raja 2013). In New York City, where more than 5.1 billion gallons of sewage was released, repercussions of the storm surge were disproportionately borne by the city's most vulnerable populations living in public housing (A. Huang 2012; Kenward, Yawitz, and Raja 2013).

Municipalities, utilities, and other organizations that design, build, and construct infrastructure have historically tended to pursue their projects without fair decision-making processes (i.e., procedural injustice), which has led to unfair distribution of risks (i.e., distributive injustice) (Balazs and Lubell 2014; Solis 2018; 2023) (see also Section 7.2, below). Viewed as a technical process, the siting, design, and construction of water and wastewater infrastructure is often left to planners, engineers, and others with specific technical expertise. Structural and systemic racism and the

10 Sewer overflow events occur in places where the underground sewer pipes that collect wastewater from homes and businesses also collect stormwater runoff from streets, buildings, and other hard surfaces. These sewer systems are called Combined Sewer Systems (CSS). Heavy rainfall can make these systems more likely to become overwhelmed both from the high volumes of stormwater and from infiltration through cracks in the pipes from other sources like groundwater.

disenfranchisement of some groups of people also contribute to the exclusion of communities of color, Tribal and Indigenous communities, and otherwise marginalized groups from water related decision making (Anguelovski et al. 2016; Braveman et al. 2022; David-Chavez and Gavin 2018; Fernandez-Bou et al. 2021).

Deeper engagement and inclusive decision making, however, can increase community support for environmental projects (Chief, Meadow, and Whyte 2016; Stober et al. 2021). For example, a national survey of households living near wind turbine projects found that citizens were more likely to have a positive attitude about a project if they felt their input had been heard by project decision makers (Firestone et al. 2018).

> The US Water Alliance suggested turning infrastructure into community assets by designing for multiple uses and benefits, offering tours and educational outreach, or creating a community space that can be a venue for art and cultural events.

Guidance is available for municipalities, utilities, and other agencies to create more inclusive, equitable processes for infrastructure siting, design, and construction. Specific to siting and designing water infrastructure, the US Water Alliance suggested turning infrastructure into community assets by designing for multiple uses and benefits, offering tours and educational outreach, or creating a community space that can be a venue for art and cultural events (Simonson 2022). This is especially helpful when the community wants and requests these kinds of multi-benefit amenities. However, multi-benefit amenities can also contribute to increased housing cost and property values, driving gentrification and displacement of local residents (Checker 2011; Wolch, Byrne, and Newell 2014). For construction, the US Water Alliance emphasized the need to minimize impacts on local neighborhoods, including dust, noise, pollution, and disrupted access to streets, parking, businesses, or other spaces. One way to minimize disruption is through the “dig once” approach where all utilities coordinate to ensure there is only a single time for tearing up streets to replace and install new underground infrastructure. Construction sites can also be used to offer economic opportunities and education, such as allowing local food vendors to set up nearby or providing educational opportunities for local schools (Simonson 2022).

Another resource from the US Water Alliance, the Racial Equity Toolkit for utilities, identifies four phases for utilities to measure where they are along the path to racial equity (US Water Alliance 2022). For capital projects, the toolkit emphasizes fully integrating resources (e.g., financial investments, staff/consultant time, data analysis and modeling, community input) to address racial disparities. Also, it suggests that utilities provide resources for education and compensation for residents who are Black, Indigenous, and other people of color to participate in all phases of capital projects. Additionally, the toolkit instructs utilities to make climate resilience a primary criterion for infrastructure project prioritization, to address community needs to identify and build climate resilience, and to implement projects that build community resilience, provide multiple benefits, and mitigate the harms of future climate impacts (US Water Alliance 2022).

There are few documented examples of inclusive, equitable processes in water and sanitation siting, design, and construction specific to climate resilience. One study that incorporated several related elements comes from a municipal wastewater treatment plant redevelopment within a marginalized, racially diverse neighborhood in San Francisco. Through participant observation and interviews with community members, utility officials, and private sector consultants, Solis (2023) documented the San Francisco Public Utilities Commission's (SFPUC) major redevelopment of the Southeast Treatment Plant (SEP) in the 2010s and analyzed how community-based organizing led to public policies that sought to improve certain environmental justice outcomes, like economic and job benefits for the community. The SFPUC states that the SEP is undergoing renovations to address regulatory requirements around nitrogen pollution, which is predicted to worsen due to climate change (San Francisco Public Utilities Commission, n.d.).

There are few documented examples of inclusive, equitable processes in water and sanitation siting, design, and construction specific to climate resilience.

The plant sits in the Bayview-Hunters Point neighborhood, which has the highest percentage of Black residents of any San Francisco neighborhood (Solis 2023). In the 1970s, neighborhood residents organized against the plant's expansion, but SFPUC proceeded anyway, enough to go from accepting 20% of the city's wastewater to 80% (Solis 2023). Waterfront property around San Francisco Bay, including the Bayview-Hunters Point neighborhood, is at risk from impacts of climate change, notably flooding during high tides, storm events, and rainfall events that coincide with high tides due to sea level rise (The City and County of San Francisco 2020). For example, analysis by the Pacific Institute showed that a power plant located in the Bayview-Hunters Point neighborhood was vulnerable to a 100-year coastal flood event with 4.5 feet (1.4 meters) of sea level rise (Heberger et al. 2012). CalEnviroScreen (v 4.0), a health screening tool from the California Office of Environmental Health Hazard Assessment, shows that, compared to other census tracts in the state, census tracts in the Bayview-Hunters Point neighborhood have elevated levels of diesel particulate matter, higher risk for childhood lead exposure in housing, and more hazardous chemical facilities and cleanup sites, groundwater threats, impaired water bodies, and solid waste sites (California Environmental Protection Agency 2021b).

In the decades following the plant's expansion, pollutants, malfunctions, and other accidents from and at the site were reported and documented, including health impacts on neighboring residents. Eventually, "[c]ity officials had to acknowledge the SEP's shameful history" (Solis 2023). Solis argued that community pressure and mobilization around the environmental justice movement helped pressure policy changes within city government in the early 2000s that "created a robust basis from which to advance procedural and distributive justice in the SEP's redevelopment planning process." Solis provided evidence for both the challenges and successes that the community continues to face in its quest for inclusion and environmental justice in the SEP redevelopment project. One problem was the displacement of long-time, predominantly Black residents due to gentrification of the neighborhood (Solis 2023). Successes ranged from representation in the SEP redevelopment advisory committee and resident surveys (both procedural justice-based successes), plans for a new community center, and apprenticeship programs. While the procedural changes ultimately helped create a more inclusive and equitable project for redevelopment, Solis explained that many distributional justice issues would not be addressed in the future, including the impacts of the multi-year reconstruction process, the lack of compensation for past harms, and SFPUC's failure to consider a more distributed and permanent solution to wastewater treatment that would reduce the ongoing burden on neighborhood residents.

Inclusive siting, design, and construction of water and sanitation infrastructure help to lay the foundation for more resilient, equitable infrastructure over the long term. Persisting in the water and sanitation infrastructure sector, however, are entrenched historical practices that fail to include or center frontline communities in decision making, systemic and structural racism, and disenfranchisement. Strategies to overcome these barriers and improve the procedural equity of water and sanitation infrastructure siting, design, and construction are:

1. **Create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience; and**
2. **Change existing or establish new processes and policies for inclusive and equitable siting and design of climate-resilient water and sanitation infrastructure with direct input from frontline communities.**

Improving the inclusiveness and consideration of climate change in the siting, design, and construction of water and sanitation infrastructure will help accelerate the achievement of equitable, climate-resilient water and sanitation in the US.

4.4 EQUITABLE, CLIMATE-RESILIENT OPERATIONS AND MAINTENANCE

Attribute description: The O&M of water and sanitation build climate resilience and ensure equitable outcomes for frontline communities.

Operations and maintenance are ongoing efforts to ensure drinking water is delivered to homes and businesses and wastewater is removed and treated appropriately. Operations and maintenance are also critical for ensuring that these systems withstand and continue to function properly under unexpected climate shocks and stresses, like those from floods, extreme heat, drought, wildfires, sea level rise, or extreme storms. The impacts of climate change will also require new approaches and considerations for decentralized water and sanitation infrastructure O&M (Calabretta, Cunningham, and Vedachalam 2022).

To be climate resilient, O&M efforts must plan to address climate change impacts directly, which means preparing for and responding to changing conditions or climate shocks as O&M tasks are regularly performed. Equitable O&M means ensuring long-term care of infrastructure to maintain performance under a variety of possible extreme weather events. The US Water Alliance added that "[s]hifting this stage of the investment cycle towards equity requires continuous tending to the organizations, people, relationship, community priorities, and processes fostered throughout all the project phases" (Simonson 2022).

Regular maintenance and inspection of water infrastructure can help identify vulnerabilities and prevent failures during and following extreme weather events (US EPA 2016a). Maintenance is also necessary to ensure that the infrastructure does not become a nuisance, or worse, a hazard to nearby communities. For example, research has documented how failed maintenance that allowed accumulation of trash in green infrastructure projects has perpetuated environmental injustice in places like Camden, NJ (Meenar, Heckert, and Adlakha 2022). In San Francisco, lack of adequate O&M of a wastewater facility became a hazard and caused health issues for a low-income community with a high proportion of people of color (Solis 2023). As climate change intensifies, O&M will become even more critical to ensuring the delivery of water and wastewater services to frontline communities.

> In remote communities, operators may not have contacts nearby or colleagues who can support them during emergencies, contributing to loss of safe access to water and adequate treatment of wastewater for the community.

Climate change not only makes performing basic O&M critical, but also needed are specific adaptations in how water and wastewater systems are managed. For example, changing hydrologic conditions may require dam operators to adjust their practices in order to balance the needs between flood control, drought resilience, human water demands, agricultural production, flows for the environment, and energy generation (Ehsani et al. 2017). Drinking water treatment engineers dealing with wildfire-impacted water sources may require new treatment approaches that alter O&M

routines and materials (Chow et al. 2019). In some parts of the country, wastewater treatment plant operators must contend with reduced flows caused by drought and necessary water reductions that increase the need for certain maintenance activities (Porse et al. 2023). To adapt to the new climate reality, wastewater treatment operators in California are changing their planning assumptions, purchasing more or different chemicals, using more energy, hiring staff, employing outside technical services, and purchasing replacement equipment sooner than expected (Porse et al. 2023).

During a climate disaster like an extreme flooding event or wildfire, water and wastewater system operators may not be able to safely perform operations activities or may not have the technical expertise for handling certain emergency situations (Payton Scally et al. 2021). In remote communities, operators may not have contacts nearby or colleagues who can support them during emergencies, contributing to loss of safe access to water and adequate treatment of wastewater for the community.

Tribes, Tribally owned utilities, and other entities responsible for water supply, drinking water and wastewater systems on Tribal lands face some unique barriers to equitable, climate-resilient O&M. Doyle and co-authors described a long list of challenges faced by Apsáalooke Water and Wastewater Authority for the Crow Tribe in Montana in improving and maintaining Tribal water and wastewater infrastructure (Doyle et al. 2018). These challenges included complex jurisdictional issues that affect all phases of water system operations, lack of authority to create water districts, and additional legal and regulatory gaps. Together, these issues can make it difficult for Tribal water and sanitation systems to raise adequate funding for O&M and capital projects. For example, while water districts are a common mechanism used by non-Tribal communities to tax and raise funds for operating and maintaining water and wastewater systems, Tribal entities are barred from taxing and raising funds in this way. Doyle et al. explained that “even if major infrastructure can be upgraded or replaced

through grants, inadequate O&M budgets mean dedicated operators are underpaid." So, when issues arise that operators lack resources, expertise, or time for, they ultimately go unaddressed (Doyle et al. 2018). Also, IHS and most other federal funding sources do not provide financial assistance for routine O&M costs (US Government Accountability Office 2018).

Another problem for Tribes is that they historically have been excluded from operating key water infrastructure that affects their well-being and water supply. Specifically, dams on Tribal lands operated and maintained by state and federal government agencies — like the Bureau of Indian Affairs, Bureau of Reclamation, or Army Corps of Engineers — have historically failed to address the interests and needs of Tribes, affecting their safety, water availability, river temperatures, erosion, land loss, and food security (Status of Tribes and Climate Change Working Group 2021).

There are fewer studies on barriers or challenges to operating and maintaining climate-resilient onsite water and sanitation systems. Calabretta et al. (2022) listed three main challenges to maintaining onsite septic systems: cost, climate, and governance issues. They reported that the cost of septic system pump-outs (a necessary activity for removing solids from a septic tank) can amount to $1,000 every three to five years and that repair and replacement of system components can cost thousands of dollars. Regarding climate change, Calabretta and co-authors stated that flooding, sea level rise, precipitation patterns, and water table changes are all major contributors to septic system failure. In the end, maintenance of these systems may not be sufficient to ensure functionality under changing climate conditions; instead, the systems may need to be redesigned or moved. Also, the authors observed that governance of onsite systems is fragmented with a patchwork of permits and regulations, yet another challenge to maintaining these systems effectively. O&M of drinking water wells and other types of onsite systems may be similarly challenged.

In the end, maintenance of these systems may not be sufficient to ensure functionality under changing climate conditions; instead, the systems may need to be redesigned or moved.

Programs and resources are available to support operators of water and wastewater systems working to improve climate-resilient infrastructure O&M (although few were found specific to equity or climate resilience). The National Rural Water Association, a nonprofit that serves water and wastewater operators in small, rural communities across the country, operates the US Department of Agriculture's Circuit Rider Program (National Rural Water Association 2020). This program provides technical, managerial, and financial assistance to rural water and wastewater systems, including O&M assistance and disaster and emergency assistance. In a review of "external support programs" for rural water supply like the Circuit Rider Program, Miller and co-authors (2019) found that these programs were associated with higher functionality, lower levels of contamination, with household satisfaction, participation, and fee payment.

Another national nonprofit, Rural Community Assistance Partnership (RCAP), provides technical assistance, training, resources, and support to private well or septic system owners and rural, Tribal, or colonias water and wastewater system operators. They are training their on-the-ground, nonprofit partners and technical assistance providers to incorporate climate resilience into their work with local systems (B. Taylor et al. 2024). In the 2024 report, *Water and Climate Equity in Rural Water Systems in the United States*, the authors specified the need for technical assistance providers to have a list of water operators in nearby regions to promote connectedness and support during times of disaster. In all states (except Mississippi), there are mutual aid networks for water operators, called Water/Wastewater Agency Response Networks (WARNs), that can provide support and aid in disaster situations to ensure ongoing operations (US EPA, OW 2023).

Online tools are also available to support climate-resilient O&M. The US EPA's Office of Water (OW) hosts periodic, free, online resilience trainings for water and wastewater utilities (US EPA, OW 2024e). Many of these are offered through an initiative called Creating Resilient Water Utilities (CRWU), which provides water, wastewater, and stormwater utilities with tools, training and technical assistance to increase system resilience to climate change (US EPA, OW 2024a). As reported in Section 4.2 above, CRWU hosts the Climate Resilience Evaluation and Awareness Tool (CREAT) that can help utility operators with climate awareness, scenario development, understanding climate consequences for assets, adaptation planning, and risk assessment (US EPA 2014a). CRWU trainings focus on how to use the CREAT tool, funding opportunities for climate resilience, and adaptation approaches. Some trainings provide attendees with Continuing Education Units (CEUs), which may be required for some water and wastewater system operators. The EPA hopes that these trainings will help utility staff practice response actions and learn where improvements are needed to increase overall preparedness. The EPA website also hosts checklists that address both climate hazards and O&M for assessing resilience in small water and wastewater utilities (defined as those serving 50,000 or less people) (US EPA, OW 2020). These checklists are designed to elicit consideration by operators and other utility system staff of the types of climate change hazards (hurricane, flood, earthquake, tornado, ice storm, fire, and other) that endanger their systems, as well as how O&M, chemical use/storage, finances, monitoring, computer equipment, and other system components may be impacted.

Incorporating equity into O&M may require different skills to those needed for addressing climate resilience. The US Water Alliance offers the following recommendation to utilities seeking to incorporate equity into their O&M:

> Prioritize infrastructure maintenance, repair, and replacement using community need and equity-based criteria, distancing the prioritization as much as possible from politically-driven requests and over-reliance on complaints that tend to be disproportionately concentrated in wealthy areas with high levels of service (Simonson 2022).

Practically, this recommendation echoes the call repeated throughout this report for direct engagement with frontline communities in decision making (see Sections 4.2, 6.2, 7.2, 9.2, and 10.2). Furthermore, it indicates that water and wastewater system operators and managers should distance prioritization of O&M activities from politics, wealth, and power and instead prioritize work that addresses long-standing inequities in service caused by racism, disinvestment, and marginalization.

Additional funding will be needed to support the changes needed to improve the climate resilience and equity of water and wastewater systems O&M. Section 8.2 will directly address the challenges with funding for climate-resilient O&M of water and sanitation systems in frontline communities.

The ongoing O&M of water and sanitation infrastructure must be equitable and climate resilient. This may require adjusting, adding, or expanding recurring tasks that operators perform to maintain infrastructure. It also means establishing protocols for how to perform O&M tasks during and just following climate emergencies. Integrating equity into water and sanitation O&M means that water and sanitation system operators need to rethink how they prioritize tasks to ensure that they address the needs of frontline communities. The strategies and approaches that can help make strides toward achieving this goal are:

1. **Identify specific O&M tasks that must be performed or adapted to protect infrastructure from climate impacts;**
2. **Put emergency response systems in place to help operators perform necessary actions during climate emergencies;**
3. **Work with technical assistance providers to perform regular O&M to ensure infrastructure remains in good condition to withstand climate disruptions;**
4. **Use materials, trainings, and tools from technical assistance providers and other supporting entities to learn about tasks needed for improving climate resilience; and**
5. **Engage directly with frontline communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.**

To achieve equitable, climate-resilient water and sanitation is to close the water and sanitation access gap in the US. Built infrastructure, like dams, water distribution systems, and treatment plants must be adapted to ensure that they can reliably function under an increasingly broad range of climate-related conditions. Through these efforts, the engineers, contractors, utilities, and other agencies that often lead the construction processes need to ensure that siting, design, and construction of water and sanitation infrastructure address climate resilience and do so equitably by including and centering frontline communities throughout the process. Finally, the ongoing O&M of water and sanitation systems needs to be made more inclusive and equitable and must help build climate resilience for communities.

To achieve equitable, climate-resilient water and sanitation is to close the water and sanitation access gap in the US.

The next category of this framework for achieving equitable, climate-resilient water and sanitation services in the US will address technology and innovation, including key barriers to equitable adoption and implementation, and the roles that different types of technologies may play in achieving this goal.

5. Technology and Innovation

This category of attributes describes how innovative technologies help to develop or expand climate resilience and equitable outcomes for water and sanitation access and systems.

Technology has long been recognized as a crucial pillar to both preparing for and adapting to the impacts of climate change (Christiansen, Olhoff, and Traerup 2011). Climate adaptation technologies are broadly defined as the application of technology to reduce vulnerability or increase the resilience of natural or human systems to the impacts of climate change (United Nations Framework Convention on Climate Change 2014). This section focuses on multiple types of water and sanitation technologies (see Table 1), including but not limited to water efficiency and reuse technologies, portable sanitation technologies, and agricultural technologies. While built infrastructure that captures, cleans, and distributes water and wastewater (such as those discussed in Section 4) can be considered technologies, this section focuses on innovative solutions beyond traditional centralized infrastructure (e.g., pipelines, reservoirs, and treatment plants) and decentralized infrastructure (e.g., septic systems). The technologies and innovations discussed in this section are designed to strengthen climate resilience and may be integrated with centralized and decentralized infrastructure or deployed independently to enhance climate adaptation capacity. Some of the technologies covered here also overlap with the natural infrastructure (NI) discussed in Section 6 (e.g., rainwater harvesting technology). A range of scales and sectors are addressed in this section, including technology implementation for households, communities, and private sector enterprises.

TABLE 1. **Examples of Water and Sanitation Technologies by Category and the Corresponding Resilience Outcomes**

CATEGORY	TECHNOLOGY EXAMPLES	CONTRIBUTIONS TO WATER AND CLIMATE RESILIENCE
Water efficiency and conservation	• High-efficiency appliances (e.g., high-efficiency toilets) • Leak detection sensors • Advanced metering infrastructure • Rainwater harvesting systems • Managed aquifer recharge	• Decrease water demand • Free up potable water supplies • Increase resilience to drought • Decrease water and energy costs
Water reuse and filtration	• Onsite greywater and wastewater reuse systems • Onsite drinking water filtration systems • Large-scale, centralized wastewater and greywater reuse systems • Desalination	• Decrease water demand • Increase resilience to drought • Diversify water sources • Decrease wastewater discharge; enhance water quality • Access to water during/ after disruptions
Sanitation	• Portable nonpiped sanitation systems • Flood-proof latrines • Composting toilets	• Access to sanitation during/ after disruptions • Decrease wastewater discharge; enhance water quality
Irrigation/ Agriculture	• Sprinkler and drip irrigation • Soil moisture sensors • Fertilizer application technologies	• Reduce water demand • Reduce use of fertilizers; reduce water contamination
Hazard/ risk preparation	• Structural barriers (e.g., dams, seawalls, levees, etc.) • Flood/drought forecasting systems • Early warning systems for floods	• Better prepare for potential disruptions to water and sanitation • Reduce/mitigate flood and drought impacts

Technologies are an important part of the solution to delivering and sustaining inclusive water and sanitation for frontline communities (WaterAid, Australian Aid, and Water for Women 2021). While improving technology for climate adaptation is a growing priority, challenges associated with its implementation and use remain, especially for frontline communities (Golovtchenko, Maher, and Shao 2024). The following attributes outline barriers and strategies to help ensure that water and sanitation technologies are equitable, safe, implemented across multiple types of water users, and result in climate resilience and affordability for frontline communities in the US. Many innovations in water and sanitation technology are a function of the management structure in place (Howard et al. 2010), tying this section closely to Section 7 on management and planning.

5.1 SUSTAINABLE, CLIMATE-RESILIENT, AND EQUITABLY IMPLEMENTED WATER TECHNOLOGIES

Attribute description: Sustainable, climate-resilient water and sanitation technologies are equitably implemented at the community level, with attention to factors such as local cultures and values, financial context, and ecological benefits.

Climate adaptation technologies offer local communities, water utilities, and state and federal agencies the opportunity to address challenges resulting from climate change (Bertule et al. 2017). However, not all communities have access to culturally and socially appropriate or economically and technically feasible climate adaptation technologies (Christiansen, Olhoff, and Traerup 2011). As such, equitable and climate-resilient water and sanitation includes accessible, sustainable, affordable, and locally supported technologies for frontline communities.

This attribute builds upon Section 4.1, which describes barriers to equitable water and sanitation infrastructure for frontline communities, including racist policies and practices along with persistent "myths" about universal access in high-income countries. Water insecurity is not confined to low-income countries, and as such, increasing attention is being directed toward low-income communities that lack access to safe and adequate water and sanitation in high-income countries (Meehan, Jurjevich, et al. 2020). For example, low-income rural communities in the US are less likely to receive water and sanitation from a centralized system compared to urban, wealthier regions (US Water Alliance 2017; Vedachalam, Male, and Broaddus 2020). Climate change is intensifying this challenge (Pacific Institute and DigDeep 2024). Centralized water and sanitation systems, like piped drinking water, are vulnerable to climate impacts because of their large-scale infrastructure and multiple points of weakness for breaks, making them less adaptable as climate change drives increased extreme weather and population mobility (Howard et al. 2010; Stoler et al. 2022).

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Decentralized technologies, like onsite reuse and rainwater harvesting, offer affordable, climate-resilient, and sustainable alternatives for low-income communities (US Water Alliance 2017). For example, in the US Virgin Islands, less than 25% of households were connected to municipal water as of 2019, but 90% had the potential to collect rainwater, which can enhance water management, reduce imports during droughts, and boost climate resilience (US EPA 2015c; Voth-Gaeddert et al. 2022). However, it is important to consider how decentralized technologies can also be vulnerable to climate change impacts due to a lack of management frameworks, funding, and technical resources, and inadequate initial construction. These factors have unintended consequences like increased unaffordability (Howard et al. 2010; 2016; Stoler et al. 2022).

Ultimately, water and sanitation technologies and innovations that can adapt to a range of climate scenarios, are financially sound, properly managed, culturally appropriate, and socially supported are encouraged to increase the climate resilience of low-income communities (Howard et al. 2010; Stoler et al. 2022). New technologies for resilience, however, are not often incorporated in these communities (Neumeyer, Santos, and Morris 2021). Numerous barriers hinder the implementation of equitable and climate-resilient water and sanitation technologies, causing the water sector to lag behind other industries in adopting innovative solutions (Ahmed et al. 2023). Table 2 below summarizes common barriers to both households and communities.

TABLE 2. Barriers to Equitable Climate, Water, and Sanitation Technologies at the Household and Community Level

GROUP	BARRIER
Household	• Upfront and maintenance costs • Lack of knowledge
Community	• Regulatory restrictions • Lack of access to capital and funding (see Section 8) • Limited data on new technologies' public health risks • Perceptions of risk • Lack of public support • Lack of technical expertise • Lack of staff capacity (see Section 10) • Coordination challenges between fragmented sectors (see Section 7.5) • Matching best suited technology with climate related challenge • A focus on symptoms rather than focus on the root cause of vulnerabilities (see Section 5.4)

Sources: Ahmed et al. 2023; Bertule et al. 2017; Christiansen, Olhoff, and Traerup 2011; Kiparsky et al. 2016; Spurlock, Davis, and Chaudhry 2023; United Nations Framework Convention on Climate Change 2014; Voth-Gaeddert et al. 2022

Achieving sustainable water and sanitation progress through technological and infrastructure innovations that address climate change requires a focus on equity, ensuring that development processes are inclusive and that the benefits of new technologies reach all communities (Osman, Hacker, and Faust 2023). Strategies to successfully and equitably apply climate-adaptation technologies in the water and sanitation sector demand the engagement and collaboration of multiple stakeholders (United Nations Framework Convention on Climate Change 2014). Some of the stakeholders and their roles in adaptation technology are outlined in Table 3. As described in Sections 7.2 and 9, local communities have the knowledge and expertise to cope with and best understand climate change impacts. As such, adaptation approaches, including technologies, will likely have more opportunities for success if informed by local knowledges,[11] ways of knowing, and values (Magee et al. 2019; McNeeley and Lazrus 2014).

TABLE 3. Stakeholders and Roles Involved in Water Sector Adaptation Technology

STAKEHOLDER	ROLE
Local communities	Deploy technologies and have contextual interaction with technologies
Research community	Develop and test new technologies
Local government	Support users and assist scaling-up small-scale or community-led technologies
National-level government	Devise necessary policies and ensure institutional capacity for technology implementation
NGOs	Research, implement, facilitate, monitor, evaluate, and finance technologies
Private sector	Secure financial resources for technologies

Source: United Nations Framework Convention on Climate Change 2014

In addition, equitable implementation of technologies requires attention to local cultures and values. One of the key challenges to engineering approaches to water and sanitation access globally is the integration of culture, perception, and behavior with advances in technology (Mihelcic et al. 2017). For equitable implementation, technologies need to be meaningful and relevant from the perspective of the communities they are intended to serve, because diverse cultural experiences shape how technical systems are adopted (Workman et al. 2021). When culture and the social realities of a specific place are not considered in water and sanitation technological approaches, more harm than good can result (see Section 5.4) (Workman et al. 2021). Approaches to climate change adaptation that are participatory and co-designed with local communities can help to understand the nuances of the relationships between culture, climate change, and adaptation strategies (McNeeley and Lazrus 2014; Workman et al. 2021).

The Indigenous Food, Energy, and Water Security and Sovereignty (Indige-FEWSS) program, a University of Arizona research project funded by the National Science Foundation, is a novel

11 Although “knowledge” is considered a singular, uncountable noun, we intentionally use the plural “knowledges” to indicate that there is no one monolithic knowledge to understand and address complex issues at the nexus of water and climate equity and that problems and solutions to address climate change require many types of knowledges from myriad disciplines and sources, including local and Indigenous knowledges.

collaboration between the university and Diné College on Navajo Nation to develop strategies for addressing water, food, and energy insecurity guided by the culture and sovereignty of the Diné people. Across the Navajo Nation, households haul water for drinking, cooking, and bathing from unregulated and contaminated sources, like livestock wells and springs (Litvack 2019). Twelve Indige-FEWSS graduate students, half of whom are Native American, along with undergraduate students from Diné College designed a solar-powered, mobile water filtration system that can clean 1,500 gallons of water per day for 30 households (Litvack 2019). This co-development of technology with the Diné community ensured its reflection of local culture and values. The program enhances climate resilience for the Navajo Nation by cleaning unregulated water sources, which will likely become increasingly important as water and sanitation resources remain scarce due to drought (Donahue 2024). For a personal account of a similar technology installed for a Navajo Nation resident and its outcomes, see the case study in Section 5.5 below.

> For equitable implementation, technologies need to be meaningful and relevant from the perspective of the communities they are intended to serve, because diverse cultural experiences shape how technical systems are adopted.

In response to climate change, innovations like the example above are becoming more common. For example, modular, adaptative, and decentralized (MAD) systems include existing and novel technologies and practices to produce, transport, store, and treat water and increase water security and climate resilience (Wutich et al. 2022). MAD technologies require coordination to achieve social justice and sustainability goals and to avoid decentralization of water and sanitation as a reactive adaptation approach (Stoler et al. 2022). Recommendations to advance equitable MAD systems include:

- Recognizing and building on social infrastructure (i.e., formal and informal institutions, social networks, and cultural values) to better align with local values and priorities and co-create pathways for new water practices and norms (Stoler et al. 2022).
- Building partnerships between MAD water and sanitation technology systems and local water and environmental authorities. Traditional power held by local water authorities can be redistributed among local actors to increase local autonomy, with care not to increase burdens on households (Stoler et al. 2022).

Comprehensive knowledge management is another strategy for ensuring that frontline communities have access to water and sanitation technology (United Nations Framework Convention on Climate Change 2014). As discussed in more detail in Section 9, water and climate adaptation requires transparent and equitable knowledge sharing between government agencies and local communities. This is true for the development, transfer, and diffusion of technologies for adaptation, especially in locations with communication barriers, literacy level differences, and unequal access to information (United Nations Framework Convention on Climate Change 2014).

Amid renewed interest in the technique of rainwater harvesting in the Southern Great Plains in response to extreme heat and variable rainfall patterns, the US Department of Agriculture Southern Plains Climate Hub partnered with the Bureau of Indian Affairs to provide tailored education and guidance to Tribes on rainwater harvesting technology (Southern Plains Climate Hub, n.d.). Approximately 150 members of historically underserved rural communities participated in the program, which provided free rainwater barrels for households. A larger rainwater harvesting project for the Alabama-Coushatta Tribe of Texas collects and stores 65,000 gallons of rainwater for wildfire mitigation, irrigation of a community garden, and dust abatement (Southern Plains Climate Hub, n.d.). In this example, the sharing of knowledge combined with technology increased frontline communities' resilience to climate impacts by decreasing water scarcity and increasing adaptability to future climate disruptions.

Water and sanitation planning and management are also key factors to ensure climate-resilient technologies are equitably implemented (see Section 7). Osman and co-authors found that decision makers in the US are interested in incorporating equity into onsite nonpotable water reuse systems (ONWS), which can add a layer of resilience against climate impacts by increasing water security and sustainability (US EPA 2020c). Yet conceptualizing and operationalizing this is challenging with such a new technology (Osman, Hacker, and Faust 2023). An equity framework that includes economic, environmental, and social equities is recommended when planning and designing ONWS to consider who can afford the technology, who is benefiting from the environmental resilience of the technology, who is included in decision making, and who has access to ONWS (Osman, Hacker, and Faust 2023).

> Despite multiple barriers for communities and households, there are strategies to ensure that low-income and historically marginalized communities are actively engaged in and benefit from the implementation of climate-resilient technologies.

The US's National Water Reuse Action Plan (WRAP), is an example of a planning effort to advance water reuse technologies and enhance community resilience to climate change (US EPA, OW 2019). The initiative involves multiple actions, including engagement with disadvantaged and rural communities, which has resulted in pilot technical assistance engagements in Idaho, California, and Kansas (Spurlock, Davis, and Chaudhry 2023). Following the conclusion of the pilot technical assistance program, two underserved communities in Idaho secured $7 million in federal pandemic relief funding to implement wastewater recycling at a combined wastewater treatment facility for both towns. The project aims to lower phosphorus levels in local waters by reducing discharge of treated wastewater effluent into waterways and increase drought resilience by providing a reliable water supply for irrigation (Spurlock, Davis, and Chaudhry 2023). This project showcases the benefits of integrating equity into climate-resilient technology planning, both for people and the surrounding environment.

Water and sanitation technologies have the potential to increase the climate resilience of frontline communities when designed and implemented equitably. This means that they are culturally appropriate, socially acceptable, affordable, sustainable, and technically feasible. Despite multiple barriers for communities and households, there are strategies to ensure that low-income and historically marginalized communities are actively engaged in and benefit from the implementation of climate-resilient technologies. These strategies include:

1. **Engage with stakeholders, with special attention to local values and cultures, when designing and implementing water and sanitation technologies and innovations;**
2. **Develop respectful partnerships between universities, technology companies, and frontline communities to co-develop technologies tailored to communities' needs;**
3. **Implement knowledge sharing about climate-resilient technologies, especially to communities with unequal access to information; and**
4. **Integrate equity-centered frameworks in the planning and design of technologies that consider environmental, economic, and social equities.**

Developing technologies that save water and reduce costs for communities at the frontlines of climate change is also key to equitable technology implementation. This topic is discussed in the next attribute.

5.2 COST-EFFECTIVE WATER-SAVING TECHNOLOGIES FOR FRONTLINE COMMUNITIES

Attribute description: Water fixture upgrades, water-saving appliances, and water reuse technologies are equitably installed to save water and reduce cost-burden on water, wastewater, and electricity bills of frontline households.

In addition to securing access to water and sanitation, technologies for water conservation, efficiency, and reuse can play a critical role in saving water and reducing household water, wastewater, and electricity bills. These same technologies also help communities avoid the rising costs of securing new water supplies, which is increasingly a challenge as climate change affects water availability (Cooley, Shimabuku, and DeMyers 2022; US EPA 2022b). For example, on average, 14% of the water treated by water systems is lost to leaks, with some systems reporting more than 60% water loss (US EPA, OW 2016). Leak detection and repair technologies — costing $277 per acre-foot of water saved — are less costly than developing new water sources, such as saltwater desalination, which costs around $2,800 per acre-foot for small projects in California (Cooley and Phurisamban 2016; Rupiper et al. 2022). At the household level, water efficient appliances and fixtures, like the EPA's WaterSense products, can reduce up to 20% of household water use and lower utility bills (US EPA, OW 2017b). For example, a high-efficiency clothes washer can save up to approximately $190 per year on combined water, wastewater, and energy bills (Cooley, Shimabuku, and DeMyers 2022).

Water and cost-saving technologies are especially important for frontline communities that disproportionately face water affordability challenges and climate change impacts (see Section 8.5). For example, climate change is tied to an increase in groundwater use and decrease in groundwater recharge, storage, and levels (Amanambu et al. 2020; Meixner et al. 2016; Pauloo et al. 2020). This can lead to increased costs, as seen by the rising pumping costs for communities reliant on the Ogallala Aquifer in the Central US, increasing uncertainty and vulnerability for rural communities

(Hanrahan 2024; Tidwell et al. 2015). To address climate change impacts and affordability challenges, equitable and climate-resilient water and sanitation systems can prioritize water- and cost-saving technologies for frontline communities.

Communities and water and wastewater utilities face a range of barriers to ensuring that frontline communities benefit from water-saving technologies. At the local level, challenges include lack of resources, capacity, and up-front buy-in from city officials, as well as legal challenges (Campbell-Ferrari et al. 2024; T. Davis 2015; Shimabuku and Snyder 2022). For example, impediments to water reuse technologies, which can improve resilience to climate change by reducing demand, include inconsistent definitions and regulations along with limited application ranges (i.e., some states restrict greywater reuse to outdoor irrigation) (Allen, Christian-Smith, and Palaniappan 2010; Yu et al. 2013). More recently, however, increased incidents of water scarcity have sparked advancements in policies, laws, and technologies that make water reuse more common (Campbell-Ferrari et al. 2024). For example, in 2023, Colorado passed a Direct Potable Reuse Policy that allows public water systems to treat and reuse wastewater as a drinking water supply.

In multifamily residential settings, adopting water-saving technologies in affordable housing may require cultural shifts, training and awareness, and staff engagement with the technology (Losoya et al. 2022; Snyder, Abraham, and Curtis 2024). Additionally, marginalized and low-income communities can struggle to participate in existing water and cost saving technology programs such as indoor and outdoor water efficiency rebates, for example. This is because of high up-front costs, long processing times for reimbursements, narrow eligibility requirements (e.g., renters in multifamily residential buildings are not always eligible), and lack of trust by those historically left out of conservation and efficiency programs (Shimabuku and Snyder 2022; WaterNow Alliance 2021b).

Strategies are available to help ensure that frontline communities benefit equitably from water and cost-saving technologies. When developing community-wide or individual household water and sanitation technologies, the strategies outlined in Section 5.1 are a great starting point to include equity considerations. Table 4 below includes additional strategies for local communities and utilities to increase awareness and uptake of conservation and efficiency technologies for low-income households, renters, and those in multifamily housing, resulting in increased climate resilience and more affordable access to water and sanitation.

TABLE 4. Strategies to Incorporate Frontline Communities in Water Efficiency and Conservation Technology Programs and Initiatives

BARRIER	STRATEGIES
Up-front costs	• Cities/utilities can partner with retailers to provide vouchers for discounts on water efficient technologies. • Cities/utilities can offer direct-install of water efficient technologies for income-qualified households. • Cities/utilities can offer free audits to identify leaks. • Cities/utilities/nongovernmental organizations (NGOs) can leverage corporate water stewardship investments to fund water-saving technologies for affordable housing.
Cultural shifts, awareness, and staff engagement	• Utilities can lead workforce development initiatives on water technologies to increase local capacity and expertise. • Cities/utilities/NGOs can engage with and educate staff on how to use, implement, and monitor new technologies.
Renters and/ or multifamily residential housing	• Multifamily water assistance credits can help keep rent prices low and distribute the cost saving benefits of water efficient technologies. • Cities/utilities can allow renters to participate in city or utility offered rebate programs with permission from property owners.
Cultural and trust issues	• Cities/utilities can partner with community-based organizations to improve customer communication and recruitment.

Sources: City of Tucson 2024; Cooley, Shimabuku, and DeMyers 2022; Losoya et al. 2022; Snyder, Abraham, and Curtis 2024

Westminster, CO, is an example of a frontline community that successfully implemented a water efficiency program to save money and increase climate resilience. A program funded by the city and implemented by AmeriCorps directly installed high-efficiency water fixtures in multifamily, affordable housing buildings. The program was funded by the City of Westminster and implemented by AmeriCorps's Mile High Youth Corps. Within the program's first year, 72 affordable housing complexes received EPA WaterSense certified technologies, including 83 new toilets, 20 kitchen aerators, eight showerheads, and 84 bathroom aerators (WaterNow Alliance 2021a). The affordable housing complexes benefited greatly from the program, with one location reducing its water use by 48%, saving $34,000 in sewer bills and $31,000 in water bills over a 12-month period (WaterNow Alliance 2021a). These cost savings can translate into greater access to affordable housing in Westminster (WaterNow Alliance 2021a). In addition to reducing demand and lowering water bills, water efficiency technologies and programs like this can enhance climate resilience in frontline communities by reducing energy use and greenhouse gas emissions and increasing adaptability to weather extremes, like drought (Alliance for Water Efficiency 2023).

Tucson's Low-Income Conservation Programs are another example of how a community can prioritize equitable water and cost saving technologies. As of 2022, Tucson had one of the highest poverty rates among 12 Western US metropolitan statistical areas, with Native Hawaiian, Pacific Islander, American Indian, and Alaska Native populations facing disproportionate rates of poverty (Making Action Possible 2022). Tucson is almost entirely dependent on the Colorado River, and drought is compromising water supply, impacting frontline communities first and foremost (City of Tucson 2023a). The city offers income-qualified households free high-efficiency toilet replacements, rainwater harvesting grants and loans, greywater harvesting grants and loans, discounted high-efficiency clothes washers, and free emergency plumbing repairs. The rainwater harvesting program is offered in partnership with the community-based organization Sonora Environmental Research Institute (SERI) and offers families up to a $1,000 grant or a $2,000 low-interest loan, depending on income (City of Tucson 2024). Having long-standing connections in the community, SERI serves as an important bridge between the city and marginalized and low-income communities to ensure that households most in need have access to rainwater harvesting technology (US Water Alliance 2017). The low-income rainwater harvesting program also offers participants up to two free trees and two shrubs, so that frontline communities benefit from increased greenery and reduced urban heat-island effects, which is critical as climate change increases extreme heat in Tucson (City of Tucson 2023a). As of 2017, Tucson's combined water conservation and efficiency programs had resulted in 15% lower water rates and combined city-wide cost savings of approximately $155 million (WaterNow Alliance 2019). As of 2022, 4,559 million gallons of water was saved across all Tucson Water's incentive programs (City of Tucson 2023b). These initiatives enhance climate resilience by ensuring

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frontline communities have access to sustainable, affordable water sources, while reducing the impacts of extreme heat and drought.

Another model comes from the Pacific Institute's project on toilet leak detection in affordable multifamily housing. Located in the city of Los Angeles, the project brought together nonprofits, a private technology company (Sensor Industries), and public water utilities, leveraging funding from Fortune 500 corporations to install toilet leak detection technology and assess water and cost savings for low-income renters (Snyder, Abraham, and Curtis 2024). Because many large multifamily residential properties have a master meter (one meter resulting in a single bill for all water used), property owners, managers, and residents can have a difficult time understanding opportunities for water and cost savings. Leak detection sensors were installed on over 1,000 toilets across eight multifamily properties, and Sensor Industries provided multiple trainings to property managers and maintenance staff on how the sensors work and how to use the online dashboard and alert system to identify, track, and fix leaks (Snyder, Abraham, and Curtis 2024). The project resulted in a 11% reduction in water use and a 12% reduction in water and wastewater costs, saving an estimated $42,380 annually, or $81 per sensor per year (Snyder, Abraham, and Curtis 2024). This reduction in water use can strengthen the community's resilience to climate change, particularly as drought conditions continue to threaten the reliability of Los Angeles' water supply (Los Angeles Regional Water Quality Control Board 2024). The benefit of reduced water and wastewater costs can be passed along to renters, lowering their financial burden for water and wastewater services. Along with assessing technology outcomes, the project included interviews with stakeholders to better understand how water conservation and efficiency improvements can be accelerated in low-income housing settings. They found that the corporate co-funding model provided housing organizations, like the Housing Authority of the City of Los Angeles, with the upfront capital needed to participate in and benefit from such a project. Additionally, incorporating an engagement and education strategy is essential to ensure that property staff consistently and effectively use leak detection technology, particularly when scaling this approach in other affordable housing communities (Snyder, Abraham, and Curtis 2024).

Water efficiency and reuse technologies are vital for reducing water bills and avoiding the high costs of securing new water supplies, especially as climate change strains resources. Frontline communities face significant barriers to accessing these technologies, such as high up-front costs and limited eligibility for rebate programs, exacerbating their vulnerability to climate impacts. Strategies that help overcome these barriers include:

1. **Develop water efficiency programs tailored to low-income residents to ensure that they benefit from cost-saving technologies;**
2. **Partner with community-based organizations to build trust within frontline communities and enhance participation in tailored low-income water efficiency programs; and**
3. **Leverage corporate investments to implement water and cost saving technologies in frontline communities, such as affordable housing complexes.**

5.3 SUSTAINABLE AND EQUITABLE WATER AND SANITATION TECHNOLOGIES IMPLEMENTED AT THE COMMERCIAL AND INDUSTRIAL SCALE

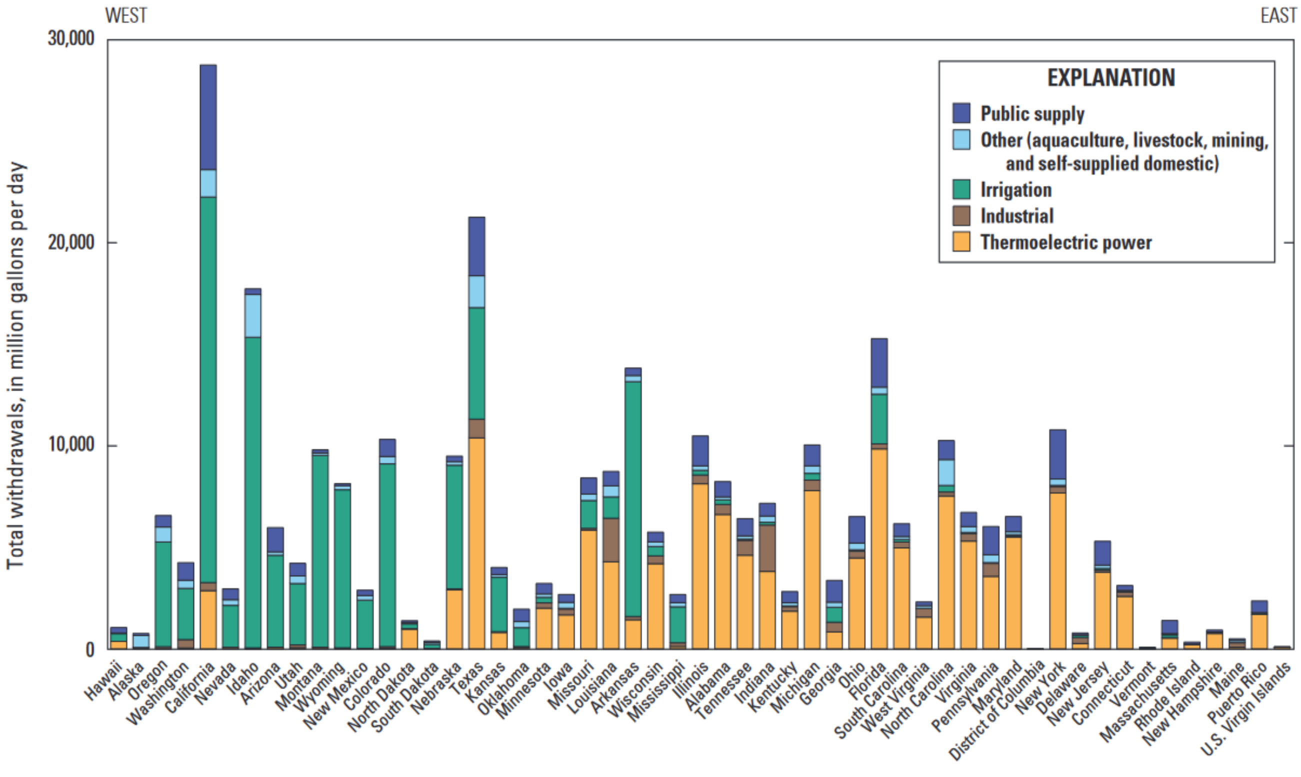
Attribute description: Sustainable water-use technologies are implemented for significant commercial and industrial users (including agriculturalists, energy suppliers, manufacturers, tourism industries, and others) and increase equity and climate resilience for frontline communities.

Declining snowpack, groundwater depletion, and water contamination are all challenges facing US communities, especially frontline communities, as climate change continues to intensify extreme weather events (Pacific Institute and DigDeep 2024). As a result, large-scale water users, such as commercial enterprises, agriculture,[12] industry, mining, and thermoelectric power plants, are critical targets for sustainable water use because they account for a substantial share of national water withdrawals and pollution. In 2015, the US Geological Survey released its most recent comprehensive water use study, which estimated that commercial, agricultural, industrial, mining, and thermoelectric power water use represented 87% of annual water withdrawals in the US (see Figure 6) (Dieter and Maupin 2017). Climate impacts to these sectors create rippling and compounding effects. For example, in rural communities dependent on water-intensive agriculture, water shortages and the subsequent decline in agricultural production can disproportionately limit the ability of individuals with fewer financial resources and educational opportunities to adapt to climate change (Sanchez, Warziniack, and Knowles 2023).

Large-scale water users, such as commercial enterprises, agriculture, industry, mining, and thermoelectric power plants, are critical targets for sustainable water use because they account for a substantial share of national water withdrawals and pollution.

12 For the purposes of this attribute, agriculture refers to large-scale commercial agriculture operations. In the US, the number of farms is declining and number of acres per farm is increasing due to consolidation (Douglas 2024; MacDonald and Hoppe 2018). This trend results in large-scale farms benefiting the most, while small-scale farmers are struggling to compete (Douglas 2024; Semuels 2019). This challenge is not discussed in-depth in this section but is an important consideration for equitable and climate-resilient water technologies for underresourced, small farmers.

Figure 6. Total Water Withdrawals by Category and State as of 2015



Source: Dieter and Maupin 2017

Large-scale water uses can also threaten water quality for frontline communities through improper dumping and waste disposal of both regulated and unregulated contaminants, as well as nonpoint source pollution from sources like agricultural runoff (Spearing-Bowen and Schneider 2017; US EPA 2015a). Climate change can exacerbate these challenges. For example, extreme events like flooding, wildfires, and sea level rise can cause pollution to be released from industrial facilities, impairing water quality (US EPA 2021a). Also, in 2024, Inside Climate News reported that Hurricane Milton's path cut through a region with over 100 facilities containing industrial waste (Price 2024). Contaminated sites are often located in or near overburdened and underresourced communities, further amplifying inequitable impacts that may worsen with climate change (Spearing-Bowen and Schneider 2017; US EPA 2021a). In another example, Robert Bullard's research on environmental racism highlighted how these decisions were closely tied to historical patterns of segregation in the southern US, particularly in the case of hazardous waste facility siting in predominantly Black communities in Houston, Texas (Bullard 2019; Mohai, Pellow, and Roberts 2009).

Commercial and industrial water users are increasingly recognizing the need to use water resources more sustainably. High-consumption sectors such as power plants, oil refineries, chemical plants, commercial agriculture, and data centers[13] are rethinking how they manage water in response to growing pressures on potable water supplies (Black & Veatch 2018; Murray 2015). However,

13 Data centers, which store, manage, and distribute data, require a significant amount of energy and water to operate. Water is necessary both directly for liquid cooling and indirectly to produce electricity (Siddik, Shehabi, and Marston 2021). For example, Google owns and operates data centers around the world for data storage and processing, with 18 locations in the US (Google, n.d.).

transitioning to new climate-resilient technologies at this scale can be difficult. For instance, a study of the barriers to ONWS identified ten common challenges to implementing the technology at commercial scale, including but not limited to a lack of supportive local regulatory programs, poor coordination among local authorities (see Section 7.5), limited knowledge (see Section 9), inconsistent water quality standards, inadequate reporting and monitoring requirements (see Section 7.6), high costs, and negative public perception (Rupiper and Loge 2019).

Similarly, barriers to industrial water efficiency can include limited time and labor resources, high project costs, difficulties in justifying return on investment, and technical complications (i.e., challenges related to existing infrastructure, such as difficulties in equipment installation or modifications to the layout) (Metropolitan Council 2018). Additionally, barriers to adopting more efficient technology in the agricultural sector include small farm size, large capital investments, lack of standards, and lack of connectivity (e.g., lack of access to broadband in rural areas) (US GAO 2019; 2024).

While the connection between commercial and industrial water technologies and climate resilience for frontline communities is underexplored, examples that increase equity and climate resilience are available to draw strategies from. This section uses examples from a few large-scale water user categories, but it is important to acknowledge that this is just a subset of the many commercial and industrial categories.

The Santa Ynez Band of Chumash Indians in Santa Ynez, CA offers a notable example of equitable and climate-resilient water technologies in a commercial and tourism context. For over 15,000 years, the Chumash lived in a region spanning 7,000 square miles (4,480,000 acres) from the coast to the San Joaquin Valley. Today the Tribe's land covers 2.38 square miles (1,526 acres) in Eastern Santa Barbara County and are home to the Chumash Casino Resort and Hotel, the largest private employer in the county with nearly 2,000 staff and over 3.5 million visitors per year (Hayden 2024; Santa Ynez Band of Chumash Indians 2022). Climate change is affecting the Tribe's water supply through warming temperatures, variable precipitation, sea level rise, wildfire, drought, and flooding — sparking concern over water use (Santa Ynez Band of Chumash Indians 2022). In response, the Tribe developed an extensive rainwater and greywater system for the casino and hotel and began producing treated water onsite in the early 2000's. Recycled water is used for landscaping, cooling tower make-up water, and toilet flushing. By 2018, water use per day dropped from a projected 90,000 gallons to just 28,000 gallons, eliminating the need to purchase municipal water (Gill 2018; Northern Arizona University, n.d.). This is a good example of how water-efficient technologies on commercial properties can enhance climate resilience of frontline communities more broadly by reducing water demand and eliminating the costs associated with securing additional water sources.

> Partnerships between public water and wastewater utilities and industries can also help advance the use of climate-resilient technologies for large-scale water users.

Sound policies are important to overcoming barriers to scaling commercial and industrial water technologies like the one above. Rupiper and Loge recommended policies that require ONWS for new construction to catalyze the creation of local programs and increase demand (Rupiper and Loge 2019). For example, San Francisco's Onsite Water Reuse for Commercial, Multi-Family, and Mixed-Use Development Ordinance requires new large developments of 100,000 square feet or more to install and operate an ONWS (San Francisco Water Power Sewer, n.d.). This resulted in numerous successful water reuse projects in the city, including a rainwater non-potable reuse system in an affordable housing development that saves 45,000 gallons of potable water annually (San Francisco Public Utilities Commission 2021). Onsite water reuse technologies advance resilience for the site as well as the community by diversifying water resources and reducing water supply constraints during drought (Snyder, Cooley, and Thebo 2023). In this case, the ordinance is a catalyst for commercial water users to implement climate-resilient technologies, which have rippling effects for the entire community, including low-income and marginalized populations.

Partnerships between public water and wastewater utilities and industries can also help advance the use of climate-resilient technologies for large-scale water users. For example, Loudoun Water, a water utility in Ashburn, Virginia, supplies reclaimed water to the county's rapidly growing data center industry. The region has become known as "data center alley" because it is home to the world's largest concentration of data centers, including companies like Google and Facebook (Dillow 2020; Loudoun County Department of Economic Development, n.d.). Data centers require a significant amount of water for direct use (e.g., cooling), and indirect use (e.g., electricity generation and electricity used in water and wastewater facilities that service data centers) (Siddik, Shehabi, and Marston 2021). A 2022 National Public Radio article reported that a mid-sized data center consumes about 300,000 gallons of water per day, equal to the use of about 1,000 US households (Copley 2022). In 2010, Loudoun Water constructed the first pipelines to distribute recycled water for industrial cooling and irrigation (Loudoun Water, n.d.). In 2023, the utility provided 815 million gallons of reclaimed water to data center customers, saving precious drinking water supply and reducing nutrients discharged into the Potomac River and Chesapeake Bay (Loudoun Water, n.d.). Using wastewater reuse technology to supply cooling water to the data centers helps reduce potable water demand, increasing the region's resilience to drought and heatwave impacts, which are becoming more intense in the US with climate change (Marvel et al. 2023). For example, in 2023, Virginia experienced a high-impact drought during the late summer and fall (National Integrated Drought Information System, n.d.). Low-income communities and communities of color are most impacted by the Chesapeake Bay's degraded waterways, especially near wastewater treatment plants (Chesapeake Bay Program, n.d.). Reducing wastewater discharge by recycling wastewater for use in data centers has the potential to contribute to enhanced water quality for Chesapeake Bay's frontline communities.

The last few decades have seen many technological advancements in agriculture, especially large-scale agriculture. These include precision agriculture technologies like in-ground sensors to measure soil moisture and nutrients, drip irrigation, and targeted spray systems, which apply resources more strategically and can reduce water use and enhance water quality by reducing the use of fertilizers (Dhillon and Moncur 2023; US GAO 2024). Irrigated agriculture is responsible for approximately 70% of global water withdrawals, making it an important water use to consider when implementing water-saving technologies (UN-Water 2018). Precision agriculture can reduce water and fertilizer use by 20% to 40% with no impact on yields (Cleary 2017). These technologies have been available since the 1990s, yet only 27% of US farms or ranches used precision agriculture practices as of 2023, likely due to high up-front costs, concerns regarding data sharing and ownership, and absence of uniform standards for the technologies (US GAO 2024).

Irrigated agriculture is responsible for approximately 70% of global water withdrawals, making it an important water use to consider when implementing water-saving technologies.

Partnerships are underway to help scale these technologies, especially in regions where frontline communities could benefit. For example, Sustainable Conservation, a nonprofit in California, is working with three San Joaquin Valley dairy farms and drip irrigation technology company Netafim USA to pilot underground drip irrigation tape (Sustainable Conservation, n.d.). The water-efficient technology uses a mixture of water and manure produced by the farms' cows, targeting nutrients to crop root zones in monitored quantities. This reduces local groundwater contamination by reducing excess use of fertilizers (Sustainable Conservation, n.d.). Residents in disadvantaged unincorporated communities in San Joaquin Valley face significant challenges obtaining clean drinking water, with the majority relying on groundwater that is polluted with nitrates from agricultural fertilizers and cow manure runoff (Lockhart, King, and Harter 2013; London et al. 2021). Climate change is intensifying these challenges by increasing the concentration of contaminants and pollutants in groundwater and surface water (Graham, Bierkens, and van Vliet 2024; Ortiz-Partida et al. 2020; Pauloo et al. 2020). The implementation of precision agriculture technologies on farms has the potential to reduce water use and enhance water quality for frontline communities, increasing both the farms' and the broader community's resilience to climate change.

To help ensure that the benefits of precision agriculture technology are equitably distributed, programs are in place to help farmers adopt sustainable irrigation methods. For example, the University of Arizona Cooperative Extension has the Water Irrigation Efficiency Program, which helps farmers and ranchers transition to efficient irrigation technology that conserves the region's dwindling water supply. The program offers grants up to $1 million per grower to convert from flood irrigation[14] to drip or sprinkler systems that reduce water use by 20% or more (University of Arizona Cooperative Extension 2022). Funded by the American Rescue Plan Act (ARPA), the program supports farmers who otherwise may not be able to afford the technology upgrades and are at risk of going out of business (Poole 2023). From the first 12 projects under the program, predicted water savings of almost 7,400 acre-feet over three years were recorded (Poole 2023). Thanks to the program, struggling farmers and ranchers who have lost access to water from the Central Arizona Project due to continued drought conditions in the Colorado River Basin can continue their operations more efficiently (Poole 2023). The conserved water not only benefits the local region but leaves water in the mainstem of the Colorado River and Lake Mead, increasing the climate resilience of the basin more broadly.

The implementation of water technologies for commercial and industrial water users presents a critical opportunity to enhance climate resilience and equity for frontline communities. By reducing water demand, decreasing runoff and discharge, and diversifying water resources, these technologies help mitigate the disproportionate impacts of climate change on marginalized groups. Strategies to equitably implement climate-resilient technologies for commercial and industrial water users include:

1. **Establish policies that promote the commercial adoption of water technologies offering broad climate-resilience benefits for communities;**
2. **Build partnerships between water and wastewater utilities and industries to implement large-scale technologies, such as water reuse systems;**
3. **Design and implement commercial and industrial water technologies and innovations collaboratively with NGOs and technology companies; and**
4. **Utilize existing support programs to scale up the implementation of innovations across commercial and industrial sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies.**

14 Flood irrigation, also known as surface irrigation, involves directing water through small trenches that run between crop rows (US Geological Survey, Water Science School 2018).

5.4 TESTED AND SAFE WATER AND SANITATION TECHNOLOGIES

Attribute description: New, innovative climate-resilient water technologies are tested and evaluated to ensure dependability and safety for frontline communities.

Climate change adaptation measures must be carefully evaluated to avoid unintended negative impacts, especially on human health and the environment (UN-Water n.d.). The Fifth US National Climate Assessment emphasized the importance of assessing tradeoffs in planning equitable and sustainable climate adaptation strategies that strengthen community resilience and self-determination (US Global Change Research Program 2023). Alongside challenges related to policies and human behavior, one common type of climate maladaptation comes from technology (Balaji 2023; Schipper 2020). Technological maladaptation occurs when innovative technologies designed to support climate change adaptation unintentionally lead to harmful outcomes (Balaji 2023).

Climate adaptation technologies that do not consider the root causes of vulnerability are more likely to result in maladaptation (Christiansen, Olhoff, and Traerup 2011; Schipper 2020). A challenge to planning climate-resilient technologies and strategies is often not just a lack of funding or project expertise, but also a lack of knowledge about the social and ecological context in which projects are being implemented (Bertana et al. 2022; Brill et al. 2022; Schipper 2020). Bertana and co-authors found when interviewing 22 climate change practitioners from across the world that the narrow focus of technological strategies often neglects social, political, cultural, and economic factors, leading to maladaptation and heightened vulnerability (Bertana et al. 2022). For instance, although this example is from outside the US, Bertana and colleagues illustrated how the restoration of canals in Bangladesh aimed at enhancing freshwater availability in response to a changing monsoon season inadvertently allowed local elites to monopolize the benefits (Bertana et al. 2022). This dynamic ultimately heightened the vulnerability of local farmers, as their access to water and rights was undermined (Bertule et al. 2017). In the US, climate adaptation technologies like proposed large seawalls are facing criticism for failing to take into consideration the communities most at risk. For example, a proposed seawall in Charleston, S.C., was critiqued for failing to protect a historically Black neighborhood, and potentially even making flooding worse in the neighborhood by blocking drainage ditches (Dembicki 2023).

> Climate adaptation technologies that do not consider the root causes of vulnerability are more likely to result in maladaptation

Other common causes of maladaptation include poor planning, overemphasis on short-term outcomes, and failure to consider changing climate or adaptation limits (United Nations Framework Convention on Climate Change 2014). Identifying potential maladaptation before it occurs is challenging and tied directly to evaluating adaptation (Schipper 2020). Schipper points out that adaptation and maladaptation are processes as well as outcomes and, as such, can change over time (Schipper 2020).

To avoid implementing well-intended water and sanitation technologies that may increase or shift vulnerabilities for communities, it is important to understand the social, economic, and cultural context of the community and to test and prove that the technologies are safe and effective before widespread implementation. For example, in Kivalina, Alaska, the Inupiat community implemented the Portable Alternative Sanitation System (PASS) pilot program, which provided portable and affordable in-home sanitation technology for households that lacked access to a sanitation system. A collaboration between the Alaska Native Tribal Health Consortium (ANTHC) and the Cold Climate Housing Research Center, the project worked with community members to test nine PASS units in 2015–2016. The units used rainwater, melted ice, or water hauled from the river, which was then used in high-efficiency toilet and sink fixtures (see Figure 7) (Alaska Native Tribal Health Consortium 2017). The system reduced the haul volume of waste by separating liquid and solid waste and disposing of liquid waste into a seepage pit. Additionally, a water treatment system provided clean water for handwashing.

FIGURE 7. Portable Alternative Sanitation System

Note: PASS system including rain catchment system (1), water storage tank (2), low flow sink and waterless urinal (3), greywater tank (4), integrated ventilation (5), separating toilet (6), and water treatment system (7).

Source: Alaska Native Tribal Health Consortium 2017

The project centered the social, cultural, economic, and physical needs of the local community in designing and piloting the system. When designing PASS, the intensifying climate change impacts on the community were a focal point (Alaska Native Tribal Health Consortium 2017). Increasing temperatures, sea level rise, extreme storms, and erosion are having devastating impacts on Kivalina and other coastal communities in Alaska, forcing some to relocate (US Climate Resilience Toolkit 2024a). The PASS technology was chosen for its mobility, as it allows the community to access critical resources and services even as they relocate, offering the most effective support in the face of climate change (Alaska Native Tribal Health Consortium 2017).

> An integrated planning and management framework, like Integrated Water Resource Management (IWRM), can be beneficial to understand the many links and potential implications of new climate adaptation water and sanitation technologies

During the pilot project, ANTHC engaged directly with homeowners through training to ensure that they understood the technology. Additionally, the pilot project included surveys and follow-up interviews to gather feedback on how the systems were working and identify areas for improvement, ensuring that future implementation continued to be tailored to the local social and cultural context and resulting in a beneficial, affordable, and safe climate-resilient technology (Alaska Native Tribal Health Consortium 2017). Based on the feedback and engineering input, the team upgraded the system after the pilot and as of 2020, 56 PASS units have been installed in six villages in rural Alaska (Alaska Department of Environmental Conservation 2020).

It is also important to consider the complexity and interconnectedness of water, climate, and equity related challenges when designing and piloting climate-resilient technologies (United Nations Framework Convention on Climate Change 2014). An integrated planning and management framework, like Integrated Water Resource Management (IWRM), can be beneficial to understand the many links and potential implications of new climate adaptation water and sanitation technologies (Bertule et al. 2017). This approach can help avoid unintended consequences of technologies, as well as maximize cost efficiency by considering equitable distribution of benefits across multiple water users and involving stakeholders in the planning and management process (Bertule et al. 2017). Assessing and implementing a technological climate adaptation strategy for safety and appropriateness in a coordinated way can be challenging in practice due to a lack of systematic planning and data fragmentation in the water sector (Bertule et al. 2017). Section 7.5 provides additional strategies on coordinated water planning and management that can be applied to water and sanitation technologies.

In the region of Hampton Roads, Virginia, where the local sanitation district used an integrated planning framework to prioritize technological strategies to address the shrinking Potomac aquifer and increase resilience to climate change (Barr 2022). Hampton Roads is experiencing some of the highest rates of sea level rise in the US, resulting in worsening and more frequent storm surge and flooding impacts on the community. Low-income and communities of color are disproportionately vulnerable to storm surges in the region (Barr 2022). The region also faces significant challenges from saltwater intrusion and land subsidence that heighten its vulnerability to sea level rise. These issues are exacerbated by the depletion of the Potomac Aquifer, a critical water source that provides approximately 155 million gallons daily (Barr 2022). Using an integrated planning framework, Hamptons Roads Sanitation District (HRSD) prioritized the Sustainable Water Initiative for Tomorrow (SWIFT), which uses water reuse technology to inject treated wastewater effluent into the aquifer (Barr 2022). The project boosts drinking water supply by replenishing the aquifer, protects groundwater from saltwater intrusion and land subsidence, reduces the amount of nutrients and sediments discharged into local waters, and ultimately increases the region's resilience to sea level rise (Barr 2022; US EPA 2020d). Using an integrated planning framework allowed HRSD to prioritize strategies in a sequence that worked best for their unique setting and conditions, avoiding forced approaches that do not fit the community's needs (Barr 2022). HRSD plans to complete the initial rollout of the program by 2030 to prove the concept and showcase larger-scale possibilities (Dill 2019).

The successful implementation of climate-resilient and equitable water and sanitation technologies depends on understanding the social, ecological, and political contexts of frontline communities. Testing and evaluating these technologies before widespread use can help prevent maladaptation and ensure that they address the root causes of vulnerability rather than merely the symptoms. Strategies to successfully test technologies before widespread implementation include:

1. **Engage the community during the pilot phase of a new technology to understand local conditions, values, cultures and needs before widespread implementation; and**
2. **Apply a systematic and integrated management approach, such as Integrated Water Resource Management, to prioritize the safe and effective deployment of climate-resilient innovations within the intricate framework of water and sanitation systems.**

Water and sanitation technologies and innovations offer significant potential to enhance the climate resilience of frontline communities, but their success depends on equitable design and implementation. These technologies must be culturally appropriate, socially acceptable, affordable, and sustainable, while also addressing the specific barriers faced by low-income and historically marginalized groups. Strategies like robust stakeholder engagement, equity-centered frameworks, and partnerships are critical to ensure that frontline communities benefit from technology and innovations. In addition, water efficiency and reuse technologies can reduce costs for frontline communities, although challenges like high upfront costs persist. Programs that involve direct-install services, community-based partnerships, and corporate investments offer pathways to overcome these barriers. Beyond residential use, commercial and industrial water users have a role in advancing equity and resilience by adopting technologies that reduce water demand and improve water quality, which can be facilitated through policies, partnerships, and support programs. Finally, the effective deployment of these innovations requires a deep understanding of local contexts and a systematic planning approach to ensure that they address root causes of vulnerability and avoid maladaptation.

Below is a case study of a single person's journey to equitable, climate-resilient water and sanitation access in their home. In this case study, we learn about Herbert's journey working with DigDeep to install an off-grid, onsite water and sanitation system that will be resilient to the changing climate.

5.5 HERBERT'S STORY — INNOVATIVE WATER TECHNOLOGY ON NAVAJO NATION[15]

Herbert, a resident of Thoreau, New Mexico, on the Navajo Nation, lived without running water for most of his life. His experience reflects a broader issue: approximately 30% of homes on the Navajo Nation lack running water, a stark illustration of the water access gap in Tribal communities.

For years, Herbert's daily routine revolved around water scarcity. He would drive 15 miles to the nearest water point, fill up several 55-gallon drums, and haul them back home. This water had to suffice for all household needs - drinking, cooking, bathing, and cleaning. During hot summers, the water would sometimes run out before the next trip, forcing difficult decisions about water usage.

Herbert's brother had previously received a Home Water System through the Navajo Water Project, which sparked hope in Herbert. In early 2023, he reached out to DigDeep's team for assistance. The process began with navigating the complex homesite lease process on his family's land, a common hurdle for many on the Navajo Nation seeking to improve their living conditions. Homesite leasing is a unique aspect of land management on the Navajo Nation, where individuals must obtain a lease from the Tribe to use a specific plot of land for their home, even if it's on their family's traditional land. This process can be lengthy and complicated, as many families may have generational homes and understandings but no official paperwork. Some people wait decades for utilities due to incomplete documentation. Once the homesite lease was secured, DigDeep's Water and Solar Technicians installed a solar-powered Home Water System at Herbert's cabin.

This system includes a 1,200-gallon water tank, a water pump, a water heater, and a septic system. The solar panels ensure that the system functions even in areas without reliable electricity, addressing multiple infrastructure gaps simultaneously.

The impact on Herbert's life was immediate and profound. Simple tasks that many take for granted, like making coffee or washing dishes, no longer require careful rationing of precious water. The ability to shower at home not only provided cleanliness, but it also restored dignity. Moreover, the time previously spent hauling water — often several hours a week — could now be redirected to other activities. For Herbert, this meant more time to enjoy simple pleasures like making coffee to enjoy on his front porch or taking in the views of the mesas surrounding his family's land.

The Home Water System also brought health benefits. With easier access to clean water, Herbert could maintain better hygiene, reducing the risk of water-borne illnesses that disproportionately affect communities without reliable water access.

As climate change threatens to exacerbate water scarcity in the already arid Southwest, solutions like Herbert's water system represent a step toward climate resilience. By providing a reliable water source at the household level, these systems offer a buffer against the uncertainties of climate change, particularly for communities that have long been overlooked by centralized water infrastructure projects. The solar-powered nature of the system ensures continued functionality even during power outages, which may become more frequent due to extreme weather events.

15 This case study was developed through direct interviews with Herbert and the DigDeep team, as well as analysis of project data and outcomes from the Navajo Water Project.

As of 2024, the project has installed over 750 home water systems, directly impacting more than 2,000 individuals. Beyond immediate access, these systems are designed to be sustainable and adaptable to changing climate conditions. They include water-efficient fixtures and are built to withstand extreme temperatures, ensuring long-term access even as the region faces increasing drought and heat waves.

These projects have been made possible through partnerships with several organizations and agencies. These include Navajo government agencies that have supported households getting their land paperwork so that they may install a home water system, IHS partners on water hauling to distant sites that have previously been unserved, chapter-level officials who passed resolutions that allowed DigDeep to work across a chapter with full buy-in from chapter leaders, and the Navajo Tribal Utility Authority, which has helped get households connected when they are near an existing mainline.

As this section on technology concludes, it's important to highlight complementary strategies that enhance water and climate resilience through more natural approaches. The next section will explore nature-based solutions and green infrastructure, which work with natural systems to address ecological challenges such as water pollution, flood mitigation, and drought resilience. Integrating these strategies alongside other technologies, or on their own, strengthens climate resilience while delivering social, environmental, and economic co-benefits to communities.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6. Natural Infrastructure

This category of attributes describes how nature and natural features and processes are used to build and protect equitable, climate-resilient water and sanitation systems and to help conserve and manage water resources.

Natural Infrastructure (NI) herein means using natural areas and systems or mimicking their processes and functions to provide environmental, economic, and cultural benefits while also supporting climate resilience (The Nature Conservancy, n.d.; National Oceanic and Atmospheric Administration n.d.; Environmental and Energy Study Institute 2019). NI can provide valuable ecosystem services not provided by conventional manmade built or "grey" infrastructure, much of which is degrading or failing in the United States (American Society of Civil Engineers 2021a). While NI is often used interchangeably with other nature-based concepts, in this report we use NI as an umbrella term to include nature-based solutions (NBS) and a spectrum of green infrastructure (GI) approaches. The most widely accepted NBS definition comes from the International Union for Conservation of Nature, which states that NBS include "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges, effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016). For more on the evolution of the definition of NBS, see Appendix C in *Benefit Accounting of Nature-Based Solutions for Watersheds Guide* (Brill et al. 2023).

Examples of NBS that contribute to climate resilience include constructed wetlands to control water pollution and mitigate flooding, natural vegetation management and restoration to reduce the impacts of floods and droughts, and sand dune restoration to protect land from stormwater surges (Oral et al. 2020; Ramírez-Agudelo et al. 2020; Woo and Han 2020; US Climate Resilience Toolkit 2024b). While not exhaustive, different types of NBS, their main functions, and a summary of select contributions to climate and water resilience are shown in Table 5.

A form of NBS is GI (though often used interchangeably), which refers to interconnected, constructed urban ecosystems and infrastructure that function together to provide a variety of benefits for water quality, quantity, biodiversity, air quality, urban heat, recreation, and beautification (Grabowski et al. 2022). Green infrastructure stands in contrast to grey infrastructure, which is defined as traditionally engineered solutions and structures such as concrete dams, seawalls, pipes, and water treatment plants (Conservation International n.d.). Green-grey infrastructure is a hybrid approach that incorporates traditional grey or engineered solutions with green infrastructure to support community resilience to climate impacts (Conservation International n.d.).

NI projects can be designed to provide multiple benefits, such as reducing water pollution, improving the hydrological health and function of watersheds, reducing flooding and combined sewer overflows, securing and regulating water supplies, protecting communities from coastal flooding, providing aesthetic and spiritual benefits, and improving human physical, mental, and social health through recreation and exercise opportunities (Cooper et al. 2016; Rowe and Bakacs 2012; Simons 2017; Vigerstol et al. 2023; Wolch, Byrne, and Newell 2014). As such, NI can be a powerful tool to advance equitable and climate resilient water and sanitation systems.

TABLE 5. Types of Natural Infrastructure at Different Scales to Increase Water and Climate Resilience

NATURAL INFRASTRUCTURE APPROACHES	FUNCTION	CONTRIBUTIONS TO WATER AND CLIMATE RESILIENCE
Neighborhood or Site-Scale		
Rainwater harvesting and use	Captures rainwater for later use for irrigation and other nonpotable activities	• Increases access to sustainable water supplies • Reduces travel time to collect water • Augments water supply during times of drought or loss of access to centralized systems due to extreme storms • Can be used to help protect property from wildfires
Green streets, bioswales, urban greenspaces, permeable pavement,and rain gardens	• Reduces urban heat island effect • Captures and filter stormwater • Allows water to infiltrate into the soil • Slows flood flows	• Mitigates local flood risks • Reduces and filters runoff to improve water quality • Increases groundwater recharge • Improves mental health and well-being • Increases access to recreation and cultural spaces
Detention ponds	• Temporarily stores stormwater runoff • Removes pollutants	• Improves water quality • Manages stormwater
Retention ponds	• Permanently stores stormwater runoff • Higher level of pollution removal than detention ponds	• Improves water quality • Manages stormwater • Creates habitat • Removes pollutants • Sequesters carbon
Green roofs	• Insulates buildings • Captures rainfall • Captures and store carbon	• Reduces heat island effect • Mitigates local flooding and reduces amount of runoff into watershed • Reduces heating-related energy costs

NATURAL INFRASTRUCTURE APPROACHES	FUNCTION	CONTRIBUTIONS TO WATER AND CLIMATE RESILIENCE
Community or Watershed-Scale		
Wildfire management and prescribed burns	• Forest thinning • Removes biomass • Improves soil stability and health	• Reduces sediment load during floods • Decreases evapotranspiration during drought • Acts as a preventative measure to mitigate against negative impacts to watersheds
Habitat protection	Protects natural landscapes	• Decreases flood and fire risks • Improves mental health and well-being by increasing access to recreation and cultural spaces
Greenways	Links habitats	• Provides networks of open spaces for recreation • Provides habitats and increase biodiversity
Setback levees	Prevents or diverts water from going to unwanted areas Increases biodiversity	• Manages flood risk • Improves water quality • Creates recreational space • Restores ecosystem • Increases biodiversity
Revegetation with native plants	Re-establishes native plants, removes invasive species	• Increases groundwater supplies • Prevents erosion and increases water absorption into soil • Improves water quality and ecosystem health • Improves biodiversity • Suppresses invasive plants
Wetland and riparian restoration and protection	• Supports regeneration after floods due to increased diversity of native flora and fauna • Captures and stores carbon and reduces methane emissions • Absorbs waves, slows flow of water across watershed, and reduces pollutants, fertilizers, and sewage runoff into waterways	• Increases water availability, dry season flows, and groundwater • Improves water quality by filtering pollutants and reduces erosion • Reduces flood risks • Provides habitat and increases biodiversity

NATURAL INFRASTRUCTURE APPROACHES	FUNCTION	CONTRIBUTIONS TO WATER AND CLIMATE RESILIENCE
Floodplain restoration	• Supports regeneration after floods due to increased diversity of native flora and fauna	• Keeps waterways healthy • Stores floodwaters to protect people and property safe • Reduces erosion • Filters water pollution • Provides habitat
Forest restoration	• Controls erosion • Increases groundwater recharge and storage • Improves surface water quantity • Regulates water flow	• Reduces wildfire risks and increases resilience • Reduces loss of headwater forests and decreases risk of degrading water quality downstream • Reduces competition for water by forest vegetation • Improves reliability of downstream municipal water supplies • Improves water quality by filtering pollutants and reduces erosion • Enhances social, economic, and ecosystem services
Agricultural best management practices	• Reduces nitrogen pollution in water ways • Reduces evapotranspiration • Improves soil health • Restores degraded cropland • Reduces unwanted animal intrusions and unwanted herbivory	• Improves water use efficiency • Improves water quality • Increases water security for small-scale farmers • Increases water availability and groundwater recharge • Decreases operational costs and increases agricultural yields • Provides multiple socio-economic benefits

Sources: Brill et al. 2023; Markus-Michalczyk and Michalczyk 2023; US Climate Resilience Toolkit, n.d.-a; Vigerstol et al. 2023; Woods Hole Coastal and Marine Science Center 2023

NI can reduce the direct exposure of people and assets to climate change hazards, such as flooding and wildfires, thereby reducing vulnerability (Vigerstol et al. 2023). These assets include water and wastewater infrastructure, such as treatment plants, which can become inundated and inoperable during flood events. When designed well, NI can also address disproportionate exposure to hazards, thereby promoting equitable climate resilience. For example, restoring forest ecosystems can increase resilience and equity by reducing direct and indirect risks associated with wildfire (e.g., water and air quality) and significantly reduce flooding impacts while protecting those most vulnerable (Davies et al. 2018; Dixon et al. 2016; Vigerstol et al. 2023). NI can further contribute to equitable climate resilience when designed to provide socioeconomic benefits for communities.

For example, agroforestry projects can reduce a community's exposure to heat, drought, floods, and erosion while also providing community members with alternative income sources from timber and non-timber products, such as fuelwood and fruit (Shackleton, Shackleton, and Shanley 2011; Vigerstol et al. 2023).

While NI can be a powerful way to advance equitable climate resilience for water and sanitation systems, it is not a panacea. There are multiple challenges involved in its implementation and ongoing management, which can include insufficient public resources and financing challenges, competition over space, and preference for engineered or "grey" solutions (Cousins 2024). NI can also produce significant tradeoffs, such as gentrification and displacement (see Section 6.3), and exacerbate, rather than address, urban inequality. This is because residents who experience disproportionate exposure to hazards such as flooding or combined sewer overflows, may no longer be able to afford to live in their neighborhoods and be displaced to areas with similar or worse environmental justice issues. In recognition of these challenges, strategies and solutions are being developed to overcome these barriers, minimize tradeoffs, and improve equity outcomes to create NI that advances equitable, climate resilient water and sanitation. These barriers and strategies are addressed in the four following attributes.

> When designed well, natural infrastructure can also address disproportionate exposure to hazards, thereby promoting equitable climate resilience.

6.1 CONSTRAINTS FOR NATURAL INFRASTRUCTURE IMPLEMENTATION REMOVED

Attribute description: Governance, policy, legal, and financial constraints for NI implementation are addressed and removed through context-specific practices to support equitable climate resilience.

While NI can advance equitable climate resilience, significant barriers to implementation prevent its realization at a larger scale (IJszenga 2021; Matthews, Lo, and Byrne 2015; Wickenberg, McCormick, and Olsson 2021). These barriers include governance, policy, legal and financial constraints, social acceptance, and cultural factors (Boelee et al. 2017; Dhakal and Chevalier 2017; Ershad Sarabi et al. 2019; IJszenga 2021; Matthews, Lo, and Byrne 2015; Roy et al. 2008). Notably, many of these challenges span geographies, scales, time, scopes, and contexts (Dhakal and Chevalier 2017). Understanding these challenges and context-specific best practices to address them is important to support implementation and maintenance of NI to advance equitable, climate resilient water and sanitation more broadly.

Governance, policy, legal, and financial constraints to the implementation of NI have been well documented in the literature. The lack of guidelines and performance standards at the federal level for NI projects can impede implementation (Copeland 2014). At the state level, water and land use policies and property rights may create additional barriers. For example, complications may arise if a proposed project has the potential to reduce the quantity of water available to downstream users and impact water rights (Copeland 2014). At the municipal level, conflicting provisions or lack of provisions in codes and guidance documents for NI can discourage implementation, often favoring a grey or engineered approach for which guidelines and ordinances are more likely to be present and well tested (Copeland 2014; Dhakal and Chevalier 2017). For example, when a solution to address stormwater is needed, municipal guidelines are more likely to be in place for large, concrete stormwater storage facilities — a grey approach — than for NI.

Traditional grey approaches to water and wastewater management, such as pipes, ditches, and wastewater treatment plants, often involve centralized governance by a single municipality (Dhakal and Chevalier 2017). By contrast, NI involves multiple partners and decentralized governance and requires a coordinated and cooperative approach between multiple stakeholders, such as public sector agencies, NGOs, funding agencies, nonprofits, community groups, and residents (Brill et al. 2022; Dhakal and Chevalier 2017). The many stakeholders involved in NI may have different and sometimes conflicting goals, which can complicate coordination and decision making. Additional NI governance challenges may arise when spanning multiple jurisdictions that have different guidelines (Dhakal and Chevalier 2017). For instance, stakeholders and decision makers may be unsure of who is responsible for different portions of management and maintenance, and budget allocations and mandates in single departments may prohibit NI investments across departments.

> Natural infrastructure involves multiple partners and decentralized governance and requires a coordinated and cooperative approach between multiple stakeholders, such as public sector agencies, NGOs, funding agencies, nonprofits, community groups, and residents.

Financial constraints and preferences for traditional grey water and wastewater management are additional impediments to the implementation of NI in both urban and rural areas. For instance, while NI can be more cost-effective than grey infrastructure in some cases, municipal funds for stormwater management often come from general revenue and are intended for grey infrastructure on public land (Dhakal and Chevalier 2017). A general lack of data on the cost-effectiveness, performance, and benefits of NI further hinders funding and financing opportunities and uptake rates among decision makers (Dhakal and Chevalier 2017; Ershad Sarabi et al. 2019; Roy et al. 2008). These financial and data constraints contribute to path dependency (a general resistance to change) among decision makers and prevent broader uptake of NI solutions for equitable and climate-resilient water and sanitation (Dhakal and Chevalier 2017; Matthews, Lo, and Byrne 2015; Roy et al. 2008). More information on the financial barriers and strategies to NI implementation is provided in Section 8.4.

While these governance, policy, legal, and financial constraints are significant, planning resources that center both equity and climate resilience are available to help overcome these challenges. For example, Termer (2024) developed a toolkit of recommended practices for NBS planning centering health, equity, justice, climate action, biodiversity, and sustainable service delivery (Termeer 2024). To address multi-stakeholder and multi-jurisdictional governance challenges at the watershed scale, the toolkit recommends developing an integrated stormwater management plan to help coordinate land use, planning, and information. For community-scale projects, the toolkit also recommends creating comprehensive policies to address equity, such as mandatory inclusionary zoning overlays within a specified distance of NBS and accountability mechanisms to ensure that economic, social, and environmental community goals are met, among others (Termeer 2024). The toolkit outlines these and other recommendations that can be attuned to local contexts to advance equitable climate resilience through the implementation of NI projects.

Although these approaches can succeed, they often require time. For example, the Blue River Action plan in the Kansas City area of Missouri has taken several decades and requires sustained coordination between water utilities and community members across multiple jurisdictions (River Network and WaterNow Alliance 2021). The Blue River crosses five counties and 21 cities. To ensure that all voices are incorporated into planning, the Heartland Conservation Alliance engages with community members to prioritize goals from regional plans to co-develop the plan, which uses NBS for habitat restoration, flood control, and public recreation.

In another example of multi-jurisdictional coordination, Martin et al. (2019) explored conditions and practices that enabled the implementation of a regional-scale NBS project that enhanced climate resilience and equity through the restoration of the Isar River — a cultural lifeline to the residents in Munich, Germany. Prior to restoration, flooding was a major concern. Large concrete banks coupled with poor water quality made the river unsafe for swimming and access was limited to residents with vehicles (Martin et al. 2019). NI strategies included reestablishing natural river morphology by removing concrete and restoring islands, using native plants to stabilize the shoreline and improve water quality, and modifying the surrounding landscape to safely accommodate flooding (Luscombe 2022; Martin et al. 2019). Equitable and safe access for recreation and social cohesion was achieved by removing concrete from the river, creating green spaces, and making access available by public transportation (Luscombe 2022; Martin et al. 2019).

A key factor in the project's success was the stakeholder engagement process, led by the Munich Water Agency. Perspectives from diverse public and private stakeholders including academics, environmental organizations, resident groups, and hydropower companies, were incorporated early on in each phase of planning and implementation. Through this process, stakeholders "co-designed" NBS features and architectural designs (Martin et al. 2019). A second innovation involved the formation of an interdisciplinary working group of local government representatives and stakeholders to address governance, policy, and legal issues. The objectives of the group were to identify and resolve conflicts, share expertise, catalyze broad support for the project, and usher in a new era of practitioners focused on NBS (Martin et al. 2019). The working group thus established trust between key stakeholders and facilitated cross-sector governance between jurisdictional levels and scales, overcoming a common implementation challenge (Dhakal and Chevalier 2017; Martin et al. 2019). Diverse and early stakeholder engagement, formation of a working group, and strong community involvement were key to addressing climate-induced flooding while increasing social equity. While this is a non-US example, these strategies could be adapted to center equity in similar projects for frontline communities in the US.

The American River Headwaters and French Meadows Forest Restoration Project, located in the Sierra Nevada mountain range, is an example of an NI project that used innovative funding mechanisms to implement a project supporting equitable and climate resilient water management, among other goals. The project planned to restore 12,000 acres of forest ecosystems through ecological thinning and biomass removal, prescribed fires, and meadow restoration and reforestation to reduce risks to the American River, home to a critical municipal watershed in the Tahoe National Forest (Storey et al. 2019). The project's inclusion of private and public lands opened opportunities for funders prioritizing restoration on private lands while sales from wood products and biomass collected during thinning provided additional revenues (Storey et al. 2019; Vigerstol et al. 2023).

Funding sources were also provided by downstream water beneficiaries, including the local water utility, private beverage companies, and landowners (Storey et al. 2019; Vigerstol et al. 2023). State, local, and federal funding, including grants, were provided by the Sierra Nevada Conservancy, California Department of Forestry and Fire Protection (under the California Climate Investments Program), and the US Forest Service (Storey et al. 2019; Vigerstol et al. 2023). Additional NI funding and financing strategies can be found in Section 8.4. While governance, policy, legal and financial barriers can inhibit the uptake of NI for equitable and climate resilient water and sanitation management, these and other strategies can be adapted in context-specific ways to facilitate planning and implementation of NI projects.

Removal of governance, policy, legal, and financial constraints is necessary to advance NI project uptake in pursuit of equitable and climate resilient water and sanitation systems. Strategies to accomplish this include:

1. **Create integrated NI management plans to coordinate knowledge and information exchange, planning, and management across departments, sectors, and jurisdictions;**
2. **Implement policies to overcome constraints to equitable NI project outcomes;**
3. **Form strong partnerships, coalitions, and interdisciplinary working groups to address conflicts and build NI project support and consensus; and**
4. **Use innovative and diverse funding solutions appropriate to the local context.**

6.2 CENTERING COMMUNITIES IN NATURAL INFRASTRUCTURE PLANNING

Attribute description: Communities, community benefits, and equity are included and centered in NI planning for climate resilience.

Centering equity, communities, and lasting community benefits in NI planning is a fundamental step in advancing equitable and climate resilient water and sanitation systems (Brill et al. 2022; Willems et al. 2020; Wilker, Rusche, and Rymsa-Fitschen 2016). Including community members in each stage of NI planning, particularly those who have been historically under-engaged or who experience disproportionate exposure to hazards, can help ensure that project design and outcomes center and deliver on these principles.

However, traditional planning and engagement mechanisms used by many projects do not center equity or meaningful community involvement in their approaches. Grabowski et al. (2023) found that only 11% of GI projects in the US define equity and over 90% do not use "inclusive processes to plan, design, implement, or evaluate GI" and may "manufacture consent with limited inclusion", demonstrating a "widespread failure of plans to conceptualize and operationalize equity planning principles." (Grabowski, McPhearson, and Pickett 2023). For example, the Atlanta BeltLine GI project engaged community members through design charettes in which residents could choose between several pre-fashioned concepts for the project (Will 2019). This commonly used engagement mechanism does not create space for residents to share their experiences or needs, limiting their influence to superficial design elements rather than addressing equity issues or planning for lasting community benefits. This is a significant barrier to the creation of equitable, climate resilient NI, because projects that do not center equity or meaningful community involvement may be more likely to reproduce, rather than alleviate inequalities (Grabowski, McPhearson, and Pickett 2023; Kitchen 2013; Roy et al. 2008).

> Centering equity, communities, and lasting community benefits in NI planning is a fundamental step in advancing equitable and climate resilient water and sanitation systems.

When robust community engagement is a part of an NI planning process, it can be difficult to implement in a meaningful way. This occurs in part due to limited practical guidance of what community engagement means, who should be involved, and how it should be conducted (Everett, Adekola, and Lamond 2023). Conventional community engagement approaches are often top-down and one-directional, in which planners convey information to residents, and do not include mechanisms for receiving or integrating community feedback (Everett, Adekola, and Lamond 2023). These approaches are the most common in NI but may not be comprehensive enough to capture the needs or priorities of diverse community members and stakeholders (Berni et al. 2022). For instance, community members' priorities for addressing stormwater overflows through GI projects may differ on the basis of age, race, length of residency, and homeowner status (Will 2019). At the same time, traditional avenues for outreach, such as social media and email, may not reach the elderly, people with low incomes, or non-English speakers, meaning that the perspectives and needs of community members within these demographics may be under-represented in NI engagement, planning, and implementation. Failure to address the needs of diverse and underserved communities in NI plans can hinder progress toward equitable climate resilience (Kitchen 2013; Roy et al. 2008).

Building trust and creating two-way engagement avenues can increase meaningful engagement with diverse voices. For example, Tucson Water partnered with the Sonora Environmental Research Institute (SERI), a trusted community partner, to build trust and increase engagement with historically underserved community members (River Network and WaterNow Alliance 2021). SERI helps Tucson Water overcome language barriers to help non-English speaking community members understand that utility programs, including a rainwater harvesting program to water shade trees, are accessible to them. Tucson Water also created a Citizens' Water Advisory Committee to support two-way engagement between residents and the utility. Communities can also engage directly in more formal ways with utilities or other agencies. In Cleveland, Ohio, where poverty rates are among the country's highest (Emily Campbell 2023), community organizations such as Cleveland's Water Champions engage with utilities as part of their regular outreach programs and as steering committee members to ensure that utility programs are based on community needs (River Network and WaterNow Alliance 2021).

Building trust and creating two-way engagement avenues can increase meaningful engagement with diverse voices.

Strategies and resources are available to help center equity, communities, and lasting community benefits in NI climate resilience planning. For example, Grabowski and co-authors (2023) noted that it can be helpful both to clearly define justice and equity in projects and ensure that communities experiencing injustices have an influence throughout the planning process. They also developed a screening tool to evaluate how well a project centers equity and communities (Grabowski, McPhearson, and Pickett 2023). For instance, the screening tool notes that a GI project that only states intention to use GI to add value to mitigate hazards is considered problematic. A more ideal project would discuss hazard distribution, its causality, and the systemic impacts of GI. The guide also states that superficial engagement — such as statements that "communities will be consulted" without concrete plans — are scored as problematic where more ideal projects list specific commitments of resources to be used in community-led deliberative processes for reparations as defined by affected communities (Grabowski, McPhearson, and Pickett 2023).

One way to engage underrepresented voices more deeply in planning is to include these community members directly in decision making, as did Harpers Ferry Water Commission in West Virginia. The commission recognized the need for a broad range of stakeholder voices in the source water protection plans for the Elk Run watershed, which provides drinking water for the local community. The commission made recommendations to the town council to open two seats on the commission to represent these communities within the watershed (River Network and WaterNow Alliance 2021).

Everett and co-authors developed a set of community engagement principles for blue-green infrastructure projects to improve climate resilience (Everett, Adekola, and Lamond 2023). Blue-green infrastructure combines and protects hydrological and ecological features to reduce vulnerability to climate change risks such as flooding, heat stress, and water shortages (Emily O'Donnell et al. 2021; Michigan Economic Development Corporation 2020). These projects can help improve water quality and reduce flood risks while providing multiple social benefits. This resource incorporates strategies to meaningfully address and negotiate hierarchical power relations in order to produce equitable, community-centered outcomes (Everett, Adekola, and Lamond 2023). These strategies include community ownership, recognition of power dynamics, actively centering the voices and needs of underserved groups, transparency to develop trust, actively promoting inputs from underserved groups, dismantling or loosening existing power relations to promote just and equitable outcomes, mutual learning from communities (particularly underserved residents), and not imposing projects from the top down (Everett, Adekola, and Lamond 2023). These principles can help guide community engagement for more equitable NI project outcomes.

In an effort to build equitable community climate resilience to flooding through GI in the Kinnickinnic River Watershed in Milwaukee, the Milwaukee Metropolitan Sewerage District partnered with Sixteenth Street Community Health Center, a local nonprofit, to engage low-income, Spanish-speaking residents experiencing disproportionate flood risk (Milwaukee Metropolitan Sewerage District 2017; The Pew Charitable Trusts 2019; Sixteenth Street Community Health Center n.d.). Sixteenth Street Community Health Center is a local institution with bilingual staff that is trusted by many area residents affected by flood risk. Partnering with a trusted institution enabled the sewerage district to engage affected community members to develop a GI plan to capture stormwater and reduce exposure to flooding. After engaging community residents, the project acquired 80 residences, removed concrete from the Kinnickinnic River, widened the river channels, created riparian zones, and landscaped steep slopes to prevent erosion (The Pew Charitable Trusts 2019; Smith Group, n.d.). The success of this partnership to engage disproportionately affected and historically under-engaged residents in the pursuit of climate resilience has led to its replication in other GI projects for flood reduction and climate resilience across Milwaukee with other organizations. While the extent to which resident goals and equity factored into each stage of planning and implementation is not clear, this type of partnership can be used to help engage and center community members in NI planning that may not participate in conventional community engagement avenues due to language barriers, lack of trust or familiarity with the hosting institution, or other reasons.

Centering communities in NI projects is fundamental to achieving equitable, climate resilient water and sanitation. Strategies to achieve this include:

1. **Clearly define justice and equity in NI projects;**
2. **Ensure communities experiencing injustice have a say throughout the planning process using two-way communication;**
3. **Incorporate transparency, trust building, and mutual learning in community engagement; and**
4. **Partner with trusted local institutions to engage hard-to-reach groups.**

6.3 NATURAL INFRASTRUCTURE PROJECTS PROACTIVELY REMOVING DISPLACEMENT RISKS

Attribute description: Potential displacement of communities in all NI programs, policies, and projects are identified and removed.

While NI can improve climate resilience and provide an array of benefits, it can also produce tradeoffs such as environmental gentrification and/or displacement of households or communities. Environmental (or green) gentrification refers to processes where environmental or sustainable practices, such as the implementation of NI to reduce climate hazards, result in increased property values that can displace low- and fixed-income residents (Checker 2011; Kuiper and Infield 2019). This means that some benefits of NI, such as reduced exposure to climate hazards and increased climate resilience come at the expense of community members who can no longer afford to live in their neighborhood (Dale and Newman 2009). Through this process, residents may experience the breakdown of critical community networks, cultural erasure, or displacement to neighborhoods with similar or worse environmental justice and climate change concerns (K. Newman and Wyly 2006). This process has also been called the "green paradox" in which measures to improve climate resilience or remediate environmental injustices through the creation of NI create new equity issues, thus preventing the realization of equitable, climate-resilient outcomes (Kuiper and Infield 2019). As such, this attribute focuses on proactively identifying and removing displacement risk through NI programs, policies, and projects.

> The incorporation of community representatives, community benefits, and equity in all stages of project planning can lead to the creation of more equitable and climate-resilient NI projects.

As noted in Section 6.2, the incorporation of community representatives, community benefits, and equity in all stages of project planning can lead to the creation of more equitable and climate-resilient NI projects. While important, these mechanisms alone are not enough to curb the impacts of green gentrification. In fact, NI projects that center equity and community engagement or that arise from grassroots community efforts can still cause significant gentrification and displacement for long-term, low- and fixed-income residents (Immergluck and Balan 2018; Will 2019). For example, the Historic Fourth Ward Park in Atlanta, Georgia, is a GI project designed to capture and filter stormwater in a retention pond to reduce flooding, reduce combined sewer overflows, and improve climate resilience (Saporta 2013; Kraatz 2020). The project came about through the advocacy of a grassroots coalition of residents and environmental activists, who advocated for a GI solution instead of a traditional grey approach, such as a sewer tunnel (Saporta 2013; Kraatz 2020). Even though the project was the outcome of community-driven efforts, it contributed to significant new luxury housing and commercial developments in the surrounding neighborhood, raised property values, and displaced many long-term and low-income residents in this historically working-class, Black neighborhood (Will 2019). Although driven by the community, the realization of greater climate resilience came at the expense of residents who could no longer afford to live there. Getting ahead of private market forces that contribute to gentrification and displacement is a significant challenge for climate-resilient NI projects that simultaneously advance equity.

In the absence of preventative policies such as rent control or inclusionary zoning ordinances, NI projects are likely to increase environmental inequality along race and class lines as property values increase and existing renters and low- or fixed-income homeowners are displaced (Gould and Lewis 2012). Though preventative policies can help mitigate the impacts of gentrification and displacement, they can be difficult to enact. For example, rent controls can be a powerful tool to help preserve affordability and mitigate gentrification, specifically for renters, but they are prohibited in certain states and cities (Dooling 2009; Klein et al. 2020). Inclusionary zoning ordinances that mandate the creation of affordable housing in new developments around NI projects can be another powerful tool to mitigate the impacts of green gentrification (Dooling 2009). If ordinances do not apply to all housing types, however, developers can find loopholes to continue to produce mid- and high-end housing options without adding affordable properties (Schenke 2018). A lack of preventative policies to mitigate gentrification and displacement from climate-resilient NI projects means that only higher-income community members who can afford to remain in or move to the area will experience the greater climate resilience afforded by these projects.

In the absence of preventative policies such as rent control or inclusionary zoning ordinances, NI projects are likely to increase environmental inequality along race and class lines as property values increase and existing renters and low- or fixed-income homeowners are displaced.

While minimizing gentrification and displacement resulting from the implementation of NI is a complex problem, strategies and toolkits have emerged to help overcome these challenges in the pursuit of equitable, climate-resilient outcomes. One toolkit developed by the Trust for Public Land outlines risk factors for green gentrification and anti-displacement options (Rigolon 2024). The toolkit's matrix of anti-displacement strategies (excerpt shown in Table 6) includes recommended actions for communities and nonprofits, as well as agencies for economic development, planning and housing, funding, and green space, plus cross-agency collaborations. Strategies include publicly owned affordable housing, protection of unsubsidized affordable housing through municipal ordinances, community land trusts, and rental assistance programs (Rigolon 2024).

TABLE 6. Anti-Displacement Strategies for Communities Undergoing Green Gentrification

AGENCY	STRATEGY	DESCRIPTION	EFFECTIVENESS
Planning and housing agencies	Rental assistance programs[42,89–91,97]	Funding for low-income renters to pay rent at times of financial hardship.	Effective in limiting eviction and displacement as a stopgap measure.[42]
Planning and housing agencies	Foreclosure assistance[42,89]	Programs providing homeowners with counseling and financial support to avoid foreclosure and displacement.	Effective in helping homeowners keep their property and avoid being displaced.[42]
Planning and housing policies	Limits to property tax increases[27,89–91,93]	Programs limiting property tax increases for low-income and fixed-income homeowners and business owners near greening projects.	A study estimated that fewer homeowners than previously anticipated could qualify for one such program in Atlanta.[98]
Planning and housing policies	Assistance to prospective homeowners[89,90,93]	Programs providing prospective homeowners with counseling and financial support to purchase a home (i.e., down payment assistance).	More than 100 new homeowners in areas near the 11th Street Bridge Park in Washington, D.C.[99] Prospective homeowners near Atlanta's BeltLine are connected with several resources and down payment assistance programs,[100]
Planning and housing agencies	Tenant right to counsel[42,87,89,90,93,97]	Programs providing legal representation to tenants in eviction cases.	Some evidence shows their effectiveness in limiting displacement.[42]
Planning and housing agencies	Just cause eviction[42,87,89,90,97]	Laws that prevent landlords from evicting renters except for specific circumstances (e.g., rent is not paid, lease terms are violated).	Effective in limiting eviction and displacement, especially for lower-income households.[42]
Economic development agencies	Local hiring and job training[27,37,87,89–93]	Programs and municipal ordinances (e.g., first-source hiring ordinances) promoting or requiring the hiring and training of residents for public capital improvement projects (including green space projects).	Mixed evidence on whether many low-income residents gain access to good employment.[99,101–106] Small impact around the Atlanta BeltLine,[106] and more promising outcomes in California's Transformative Climate Communities program [101–105] and Washington, D.C.'s 11th Street Bridge Park.[99]

Source: Excerpted from Rigolon 2024[16]

Another toolkit titled Community-Centered Solutions for Green Gentrification and Displacement centers the Black, Indigenous, people of color, and low-income residents and communities that face the most extreme climate impacts (River Network 2024). The toolkit's creators posited that, to build equitable climate resilience, NI projects must center anti-displacement strategies. The toolkit provides resources for building community trust, setting project intentions, and strategies

16 Footnotes in the table correspond to citations within (Rigolon 2024).

for addressing risks and barriers (River Network 2024). The toolkit also includes case studies of innovative approaches to address displacement in NI plans, such as the Mott Haven-Port Morris Waterfront Plan.

The Mott Haven-Port Morris Waterfront Plan is a community-envisioned and community-managed plan created with local stakeholders and city and state agencies in the South Bronx in New York City (River Network 2024). The plan uses NI to increase resilience to climate change impacts such as flooding and heat risks. Using a community land trust model, a community center will be created to house community health, education, and workforce development services. The project incorporates equitable development principles — including for jobs, housing, and environmental justice — and centers green space equity through policy change activism and a tool that will allow frontline communities to assess the value of green spaces in their community (River Network 2024).

While the impacts of this framework on gentrification and displacement are unclear, the project seeks to reduce tradeoffs for frontline communities while promoting climate resilience through NI. These and other resources are available to help recenter underserved communities and the tradeoffs of NI to create nuanced projects that both advance equity and climate resilience. Advancing equitable and climate resilient water and sanitation through NI requires proactive steps to address gentrification and displacement risks spurred by project implementation. Strategies to accomplish this include:

1. **Utilize and adapt existing toolkits to identify local risk factors for displacement and to evaluate the strength of anti-displacement strategies;**
2. **Implement locally appropriate and feasible anti-gentrification and displacement policies prior to project construction; and**
3. **Co-create equity scorecards with residents and other stakeholders to evaluate how well an NI project mitigates gentrification and displacement.**

6.4 NATURAL INFRASTRUCTURE BENEFITS VALUED FOR ACHIEVING EQUITABLE CLIMATE RESILIENCE

Attribute description: Context-specific approaches to the valuation of NI for equitable, climate-resilient water and sanitation are used in decision making.

NI can provide ecosystem services, or “direct and indirect benefits that ecosystems provide humans,” which can be valued to demonstrate NI’s contributions to equitable and climate resilient water and sanitation systems (US Department of Agriculture, n.d.-b; Mok et al. 2021). A list of ecosystem services can be found in Table 7. Given the urgent need for increased climate resilience, many advocate for the economic valuation of NI ecosystem services to support their uptake (Mok et al. 2021; Van Oijstaeijen, Van Passel, and Cools 2020; Wild, Henneberry, and Gill 2017). Economic valuation of ecosystem services is seen as a way to demonstrate the usefulness of NI and can be used as a tool to support decision making, to understand the types of NI that would be economically viable, and to increase public support (Vandermeulen et al. 2011; Van Oijstaeijen, Van Passel, and

Cools 2020; Wild, Henneberry, and Gill 2017; Wilker and Rusche 2014; Mok et al. 2021). While valuing the benefits of NI can support their uptake for equitable and climate resilient water and sanitation management, the development and use of valuation systems comes with several challenges and tradeoffs.

TABLE 7. Types of Ecosystem Services and the Benefits They Provide

List of ecosystem services (based upon Ehrlich and Ehrlich, 1981; Costanza et al., 1997; De Groot et al., 2002; Millennium Ecosystem Assessment, 2003)

Category	Definition	Examples of goods and services provided
Production services	Production services reflect goods and services *produced* in the ecosystem.	Provision of: –Food –Fodder (including grass from pastures) –Fuel (including wood and dung) –Timber, fibers and other raw materials –Biochemical and medicinal resources –Genetic resources –Ornamentals
Regulation services	Regulation services result from the capacity of ecosystems to regulate climate, hydrological and bio-chemical cycles, earth surface processes, and a variety of biological processes.	–Carbon sequestration –Climate regulation through regulation of albedo, temperature and rainfall patterns –Regulation of the timing and volume of river and ground water flows –Protection against floods by coastal or riparian systems –Regulation of erosion and sedimentation –Regulation of species reproduction (nursery function) –Breakdown of excess nutrients and pollution –Pollination –Regulation of pests and pathogens –Protection against storms –Protection against noise and dust –Biological nitrogen fixation (BNF)
Cultural services	Cultural services relate to the benefits people obtain from ecosystems through recreation, cognitive development, relaxation, and spiritual reflection.	–Nature and biodiversity (provision of a habitat for wild plant and animal species) –Provision of cultural, historical and religious heritage (e.g., a historical landscape or a sacred forests) –Provision of scientific and educational information –Provision of opportunities for recreation and tourism –Provision of attractive landscape features enhancing housing and living conditions (amenity service) –Provision of other information (e.g., cultural or artistic inspiration)

Source: Reprinted from Ecological Economies, Vol 57, Hein et al., Spatial scales, stakeholders and the valuation of ecosystem services, Copyright (2005), with permission from Elsevier.

A significant challenge here is the lack of standardized methods and tools to identify, account for, and value the benefits of NI (Brill et al. 2023). In particular, sourcing data that value only parts of the spectrum of ecosystem services is problematic. This makes it difficult to communicate the full range of project benefits through a single valuation system (Bassi et al. 2020). These data gaps contribute to biases and limitations within individual valuation models, meaning that one framework may highlight and value particular ecosystem services, such as water quality or disaster risk reduction, while leaving out other benefits, such as long-term climate resilience or impacts on local livelihoods (Kuhl and Boyle 2021). When the full range of benefits and co-benefits of NI are not well understood, assessed, or communicated through valuation, investors may pass on these projects.

It is also difficult for a single valuation system to contextualize the benefits and tradeoffs NI create for different stakeholders (Mok et al. 2021; Wild, Henneberry, and Gill 2017). This barrier has important equity implications as many valuation systems do not illustrate the equitable or inequitable distribution of benefits and tradeoffs for different demographics, stakeholders, or sectors. While every NI project will produce some tradeoffs, as discussed in Sections 6.2 and 6.3, it is vital that tradeoffs are not disproportionately borne by frontline communities.

Although valuation of nature and ecosystem services is difficult, more comprehensive valuation models have been developed that can support the uptake of NI for climate-resilient water and sanitation systems. These include frameworks such as NBS Benefits Explorer, WaterProof, and SAVi, which assess and value the impact of NI projects on climate resilience, local livelihoods, and human health and well-being. For example, the SAVi valuation model was used to analyze the economic, environmental, social, and financial viability of wetland restoration in Senegal's Saloum Delta, a valuable economic resource for local communities (Bassi et al. 2020). Climate change and unsustainable use of mangroves is causing coastal erosion and salination, which compromises the livelihoods of residents. Accordingly, the framework was used to provide economic valuation of the ecosystem services provided by the delta's wetlands and mangroves for local livelihoods and regional development, including co-benefits such as income generation. The framework used a range of scenarios, including NI restoration, and showed how these scenarios will affect the economic contribution of the Delta over time. The framework demonstrates that, without mangrove reforestation, the quality of the wetland will decrease over time, harming local livelihoods, human well-being, and regional development across multiple sectors and stakeholders including agriculture, fisheries, energy, and infrastructure (Bassi et al. 2020). This comprehensive valuation of ecosystem services provided by the delta demonstrates the importance of climate resilient wetlands and mangroves for local livelihoods, as well as the value of NI projects to achieve long-term social and ecological well-being.

Although valuation of nature and ecosystem services is difficult, more comprehensive valuation models have been developed that can support the uptake of NI for climate-resilient water and sanitation systems.

The SAVi valuation model has also been used to value the climate risks of increased flooding and stormwater on infrastructure and human health and well-being, as demonstrated in a project focused on Johannesburg, South Africa (Wuennenberg, Bassi, and Pallaske 2021). It has also been used to value and develop support for long-term conservation of Lake Dal in Srinagar, India, through implementation of NI (including a constructed wetland) and grey infrastructure (including upgraded sewage treatment) to address local residents' water and sanitation concerns (Bassi et al. 2018). SAVi and other comprehensive valuation models can be used to demonstrate the costly impacts of climate change on water and sanitation, ecosystems, and local livelihoods in addition to the climate resilience and cost savings NI can provide to address these concerns.

SAVi and other comprehensive valuation models can be developed to simultaneously center climate resilience, human well-being, and the impacts of climate change and NI projects on multiple sectors and stakeholders. Although these valuation systems can demonstrate the value of NI for climate-resilient water and sanitation and human well-being, they may not explicitly center equity nor the tradeoffs experienced by different social groups. In such instances, comprehensive NI valuation models can be bolstered by the incorporation guidelines and recommendations created to center equitable outcomes. For example, Kallis et al. (2013) created a set of equity guidelines for ecosystem valuation. Existing as a set of questions, the guideline asks of a project:

1. **Will it improve the environmental conditions at stake? (additionality);**
2. **Will it reduce inequalities and redistribute power? (equality);**
3. **Is it likely to suppress other languages and valuation and value-articulating institutions? (complexity building); and**
4. **Will it serve processes of enclosure of the commons? (accumulation by dispossession/neoliberalism).**

These questions can be applied to comprehensive NI valuation models to more explicitly center equity in assessments because they prompt inquiry about tradeoffs and the distribution of benefits through an equity lens.

Further, Chausson and co-authors offered four key recommendations to value NBS outcomes beyond market valuations in order to foster “more just, equitable, and environmentally sustainable pathways” (Chausson et al. 2023). These recommendations can be explored alongside valuation models to center equity in the valuation of NI for climate resilient water and sanitation. The first recommendation is to recognize NBS as place-based partnerships between people and nature. Thus, rather than equating NBS to natural capital, NBS are seen as human-nature relationships that can simultaneously address ecological and social challenges. The second recommendation is to recognize the role of Indigenous Peoples and Local Communities (IPLC) as leaders of NBS. Rather than viewing IPLC as subjects to be employed or partners to deliver their vision of a nature-based economy, which can reinforce power asymmetries, IPLC are regarded as active leaders. This requires going beyond superficial representation of IPLC and addressing existing power imbalances by creating the conditions for IPLCs to shape solutions based on their needs and perspectives. The third recommendation is to recognize alternative modes of finance. Strategies associated with this recommendation include taxing environmentally harmful activities, using decolonial finance methods such as unconditional cash transfers or debt-relief schemes, and repurposing harmful government subsidies, as seen with the environmental land management scheme in England, designed to provide financial gifts to sustainable farmland stewards. (For more on financing strategies for NI see Section 8.4.) The fourth and last recommendation is to shift away from the imperative for economic growth, stressing that NBS should not be used as a tool to promote a perpetual growth agenda. Noting that growth can be appropriate, for instance to support more sustainable modes of development in lower-income areas, NBS should be used to promote ecological and human well-being, rather than “nature-based economic growth” (Chausson et al. 2023). These principles can be used to emphasize equity in the creation and promotion of NI to provide more equitable and climate-resilient water and sanitation outcomes.

Valuing NI is an important step in promoting the uptake of NI projects for equitable and climate-resilient water and sanitation systems. Strategies to achieve this include:

1. **Utilize comprehensive valuation models that center climate resilience, human and ecological well-being, and impacts for multiple sectors and stakeholders;**
2. **Incorporate equity-centered guidelines alongside valuation models to understand the distribution of tradeoffs and benefits for frontline communities; and**
3. **Incorporate non-market-based valuations and recommendations that center equity.**

In conclusion, NI has great potential to enhance the climate resilience of water and sanitation systems. However, they must be equitably designed and implemented. Barriers to NI implementation can prevent their uptake at a greater scale but can be overcome through strategies such as integrated management plans, the formation of strong partnerships and interdisciplinary working groups, and the use of comprehensive valuation models. Because NI projects come with tradeoffs, care is needed to ensure that equity and community benefits are central to decision making and that tradeoffs do not disproportionately accrue to frontline communities and underserved residents. Approaches such as centering impacted communities in decision making, building trust with local communities, and implementing anti-displacement policies are critical to ensuring that frontline communities benefit from these projects. Ultimately, attention to local context and impacted communities is critical to achieving equitable and climate-resilient water and sanitation.

7. Management and Planning

This category of attributes describes how equity is centered in how environmental protections, community input, financial sustainability, climate impacts and risks, multi-sector coordination, and monitoring and evaluation are incorporated into planning and management of water and sanitation access.

Equitable, climate-resilient water and sanitation require that management and planning empower frontline communities to withstand, adjust, and evolve amid the uncertainties and challenges posed by climate change (WaterAid, Australian Aid, and Water for Women 2021). Better planning and water management are key strategies for adapting to climate change, yet equity is lacking in US cities' climate action plans (US Water Alliance 2017; UN-Water n.d.). Although climate change is increasingly being incorporated into water resource management planning, this is not always the standard approach nor is it always straightforward (John et al. 2020; Kolokytha, de Oliveira Galvão, and Teegavarapu 2017). Water and sanitation systems and local, state, and federal agencies can develop climate-resilient and equitable strategies so that their planning and management efforts prioritize safe, affordable, acceptable, sufficient, and accessible water and sanitation for all.

This section includes six attributes of water and sanitation management and planning that center equity and are critical for climate-resilient outcomes for frontline communities. These include

1. Source water protections are incorporated into water, sanitation, and climate plans and programs;
2. Frontline communities are centered in climate, water, and sanitation planning and management;
3. Water and sanitation providers are financially sound in the face of climate change;
4. Water and sanitation systems are prepared for climate disasters and inequitable impacts;
5. Cross-sectoral coordination happens to achieve equitable, climate-resilient water and sanitation; and
6. Equitable, climate-resilient planning and management is continually monitored and evaluated for effectiveness.

7.1 SOURCE WATER PROTECTIONS INCORPORATED INTO WATER, SANITATION, AND CLIMATE PLANS AND PROGRAMS

Attribute description: Source water and other environmental protections are part of water and sanitation planning and management to increase frontline communities' resilience to climate change.

Millions of people lack access to safe water and sanitation services, with source water[17] contamination a contributing factor (US Water Alliance 2017). Source water protection involves reducing or preventing potential risks and impacts to drinking water supplies (American Water Works Association 2018). Equitable water management is proactive in connecting source water and water quality to ensure that marginalized and underresourced communities have access to clean drinking water and sanitation (US Water Alliance 2017). Climate change is intensifying multiple phenomena that can negatively impact the quality and quantity of source water, including drought, flooding, wildfire, extreme temperatures, sea level rise, and extreme storms (Marvel et al. 2023). For example, climate change is decreasing seasonal snowpack, portending a low- to no-snow future in parts of the Western US, which could be catastrophic for Western water systems (Siirila-Woodburn et al. 2021).

Source water and environmental protections that safeguard drinking water in areas facing legacies of water quality challenges and climate change impacts are critical for resilient and equitable water and sanitation.

Communities experiencing systemic racism and discrimination, poverty, and financial strain face disproportional water supply challenges (Cross 2001; Davies et al. 2018). Scanlon and co-authors (2023) found that communities with higher social vulnerabilities are disproportionately impacted by health-based drinking water quality violations. For example, in addition to lacking water infrastructure (see Section 4.1), the Navajo Nation faces contaminated groundwater because of years of mining on and around the reservation (Hoover et al. 2017; Pietz and Zeisler-Vralsted 2021). Climate change is exacerbating source water challenges by increasing the frequency and intensity of extreme weather events, which impact frontline communities disproportionately (Pacific Institute and DigDeep 2024). This can be seen in the aftermath of wildfires that affect communities of color unequally (Davies et al. 2018). Wildfires are increasing with climate change and lead to contaminated and unsafe water supplies in affected watersheds (Pacific Institute and DigDeep 2024; Robinne et al. 2021; Domke et al. 2023). Additionally, droughts exacerbated by climate change are straining water supplies, especially for frontline communities (Feinstein et al. 2017).

Source water and environmental protections that safeguard drinking water in areas facing legacies of water quality challenges and climate change impacts are critical for resilient and equitable water and sanitation. Additionally, source water protection can provide many benefits beyond water

17 Source water includes natural bodies of water, such as rivers, streams, lakes, reservoirs, springs, and groundwater, that supply water to both public drinking water systems and private wells (US EPA, OW 2015a).

security, including but not limited to habitat and ecosystem protection, improved preparedness and response capacity for emergency events, improved long-term management of natural infrastructure (NI), climate change mitigation and adaptation, and human health and well-being (American Water Works Association 2018; Abell et al. 2017).

States, cities, utilities, Tribes, and other groups responsible for source water planning and management face a range of challenges. First, states report that the leading cause of water quality problems is nonpoint source (NPS) pollution, which comes from many diffuse sources like agriculture runoff, mining, and urban runoff (US EPA 2015a). NPS pollution impacts on source water can be challenging to plan for and manage because effects vary and are not always fully understood (US EPA 2015a). A list of additional barriers water systems encounter when implementing source water protection programs is included in Table 8.

TABLE 8. Common Challenges Drinking Water Utilities Face in Implementing Source Water Protection Programs

CHALLENGE	DESCRIPTION
Limited Resources and Capacity (see Section 10)	Smaller water systems often struggle with the staff, technical capacity, and sustained funding needed for long-term source water protection and comprehensive data collection and analysis.
Economic Justification	Building a strong case for source water protection requires clear quantification of economic benefits, but it can be challenging to address the perspectives of various stakeholders, including drinking water systems, public officials, and the public.
Lack of Jurisdiction	The water system's authority to undertake source water protection activities may be limited due to jurisdictional constraints over protection areas.
Lack of Agreement	It may be difficult to reach a consensus on the causes of source water pollution and the best measures to address them.
Lack of Knowledge (see Section 9)	Understanding among water system staff and key stakeholders of source water protection and its associated costs and benefits may be limited.
Competing Economic, Environmental, and Community Priorities	Complex economic, environmental, and community priorities in funding and management may conflict, along with lack of agreement on their relative importance.
Limited Cross-Sector Engagement (see Section 7.5)	Limited cross-sector collaboration, particularly among drinking water, wastewater, and stormwater operations, may require greater effort to gain support for proposed activities and lead to conflicting or redundant efforts in source water protection.

Source: Adapted from American Water Works Association 2018

An additional barrier to equitable and climate-resilient source water protection planning is the lack of easily accessible information and data at the nexus of water, equity, and climate change. Environmental and climate justice tools like the White House Climate and Economic Justice Screening Tool (CEJST) and the EPA's Environmental Justice Screening and Mapping Tool (EJScreen) are important instruments for source water protection but lack some specificity regarding drinking water quality (Scanlon et al. 2023).[18] For example, CEJST had a water category that was limited to proximity to point-source contamination (i.e., wastewater discharges), but nonpoint source contamination data were missing (Scanlon et al. 2023). However recent updates to EPA's EJScreen included the addition of drinking water noncompliance and private drinking wells, which are helpful for water and sanitation planners to better understand the spatial distribution of water quality challenges and inequities (US EPA 2024e). Additionally, states' reliance on socioeconomic factors (e.g., median household income) rather than environmental justice factors, like race, to define disadvantaged communities (DACs) for federal funding through the Bipartisan Infrastructure Law can hinder planning and funding for climate-resilient source water protection programs focused on frontline communities (Scanlon et al. 2023).[19] CEJST included demographics like race and age when identifying DACs, providing water planners and managers the opportunity to identify source water protection priorities that include climate resilience and justice (Council on Environmental Quality, n.d.).

One strategy for incorporating source water quality and environmental protections into equitable water and sanitation planning and management involves the revitalization and remediation of urban riverfronts, lakes, bays, deltas, and ports as an opportunity to address water quality issues and create benefits for frontline communities (US Water Alliance 2017). For example, Groundwork USA is working with DACs to clean up brownfields and install green infrastructure and daylight creeks[20] and create greenway parks along waterways (US Water Alliance 2017). Not only does this approach protect source water and enhance access to clean water for frontline communities, but NI increases climate resilience by lowering flood risk, reducing urban heat island effect, reducing energy needs for managing stormwater, and protecting coastal areas from erosion (US EPA, OW 2015b).

To advance climate resilience and equity and reduce uncertainty and address dwindling source water quantity challenges, as seen in the Western US due to climate-related declining snowpack, water managers and planners can develop and include physical strategies and technologies like increased storage, managed aquifer recharge, demand reduction programs, and real time modeling in plans and programs (Siirila-Woodburn et al. 2021). For example, for rural or low-income communities in California's Central Valley that have been disproportionately affected by climate change, managed aquifer recharge can provide multiple hydrological, socioeconomic, and socio-ecological benefits by enhancing equitable access to groundwater resources (Marwaha et al. 2021). See Section 5 above for more details on climate-resilient and equitable water and sanitation technologies and innovations.

Alongside physical and scientific mechanisms for reducing uncertainty in source water quantity, water planners and managers can deploy strategies that account for uncertainty and ensure that hydrologic information is translated into decision making and policy. A co-production framework that includes scientists, water managers, and community stakeholders can help produce science that is use-inspired and influenced by the needs of frontline communities (McNeeley et al. 2018; Siirila-

18 As of February 2025, CEJST and EJScreen are no longer available under the new federal administration. You can access both tools through the Public Environmental Data Project here. You can also access an archived version of CEJST here, and EJScreen here.

19 Disadvantaged community (DAC) is also a term used by the federal government under the Safe Drinking Water Act and Clean Water Act to designate communities that are marginalized, underserved, and overburdened by pollution.

20 Daylighting creeks is the process of uncovering buried streams, restoring their natural flow above ground.

Woodburn et al. 2021). For example, the Eastern Shoshone and Northern Arapaho Tribes of the Wind River Indian Reservation in Wyoming partnered with university partners and government agencies to co-produce early-warning tools for drought and climate adaptation planning around needs identified by the Tribes, resulting in climate adaptation and source water protection that is tailored to these frontline communities' needs (see Section 7.2 for more detail) (McNeeley et al. 2018).

Lastly, managers and planners can support the education and awareness of private well testing to help ensure that groundwater is safe, especially in the face of climate change. This is critical because state and local requirements for private well water users are often insufficient to protect users from Safe Drinking Water Act violations (Schmitt et al. 2024). Water and sanitation users, however, may not have the capacity to participate in practice or behavior changes, like well testing and monitoring, due to lack of time, financial resources, or knowledge of water safety issues (Flanagan et al. 2016). Yet gathering this information is crucial, as climate impacts like heavy rainfall, drought, and wildfires can contaminate wells with pollutants (Pacific Institute and DigDeep 2024; Pauloo et al. 2020). A case study in New Jersey and Maine showed that government-sponsored testing initiatives, like public meetings, newsletters, and free testing kits, significantly increased well testing rates (Flanagan et al. 2016). Managers and planners can boost household resilience to climate impacts by integrating education and awareness programs into source water quality frameworks with benefits for frontline communities facing financial and knowledge barriers.

> Alongside physical and scientific mechanisms for reducing uncertainty in source water quantity, water planners and managers can deploy strategies that account for uncertainty and ensure that hydrologic information is translated into decision making and policy.

Resources are available to help water and sanitation systems include source water protections in their plans and programs. The EPA's Source Water Protection Program includes a range of tools, including technical and planning assistance, coordination, education, outreach, facilitation guidance, and details on source water protection and climate resilience. The program emphasizes the importance of including source water protection in emergency preparedness and response planning to identify and address climate-related risks to drinking water sources (see Section 7.4) (US EPA, OW 2024f). The EPA also houses multiple resources on its Source Water Protection webpage, including details on partnerships, source water assessment and planning, and Tribal source water protection projects.

One such project is San Carlos Apache Tribe's work to reduce nonpoint source pollution from rangeland agriculture and habitat modification in the Bear Gulch Creek watershed, which contains Hills Springs, a wetland and spring that provides source water for the Tribe (US EPA, OW 2022c). The Tribe is fencing the perimeter of Hill Springs to exclude livestock from grazing the springs and replanting trees and plants to improve riparian habitat. The project is expected to reduce bacteria levels in the spring discharges and protect fish and wildlife habitat, which are culturally vital to the San Carlos Apache Tribe (US EPA, OW 2022c). Protecting the Tribe's spring source water is increasingly important as warmer temperatures and reduced precipitation are causing water supplies in the region to shrink (Messick 2023).

Integrating source water and environmental protections into water and sanitation planning and management is essential to fostering climate resilience for frontline communities. Key strategies to accomplish this are:

1. **Use remediation projects as an opportunity to implement NI that protects source water quality for frontline communities;**
2. **Include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security;**
3. **Collaborate with frontline communities, scientists, and managers to co-produce tools, plans, and programs that safeguard source water; and**
4. **Integrate education, awareness, and support for private well water quality testing into management frameworks.**

A key component of effective and inclusive source water protection planning is engagement with frontline communities, which is described in more detail in the next attribute.

7.2 FRONTLINE COMMUNITIES CENTERED IN CLIMATE, WATER, AND SANITATION PLANNING AND MANAGEMENT

Attribute description: Equitable involvement and empowerment of community members in planning and management are reflected by centering frontline communities' priorities.

Climate change impacts are placing a disproportionate burden on frontline communities' access to water and sanitation (Pacific Institute and DigDeep 2024). Local stakeholders are best suited to understand the impacts of climate change on their communities as well as opportunities for adaptation. This is because of their close connection to the specific climate-related challenges in their region, along with a deep understanding of the socioeconomic vulnerabilities and water insecurity they face (McNeeley and Lazrus 2014; WaterAid 2021). Water and sanitation planning and management will be best positioned to equitably advance climate resilience when centered around frontline communities' priorities by involving and empowering their perspectives, expertise, and values in decision-making processes (B. Taylor et al. 2024).

Effective and transformative water and sanitation management strategies are deeply rooted in local cultures, representative of the communities they serve, and achieved through substantial participation by marginalized groups (Howard et al. 2021). Increasingly, global scientific and practitioner communities are formally recognizing Indigenous knowledge systems as vital for humanity's ability to adapt to extreme climate fluctuations (David-Chavez and Gavin 2018). Research has found that climate adaptation planning has often failed to meaningfully include frontline communities (Anguelovski et al. 2016; David-Chavez and Gavin 2018; Fernandez-Bou et al. 2021).

Distributional justice (i.e., the equitable outcomes of adaptation processes) in adaptation planning tends to be the focus, while procedural justice (i.e., fairness and inclusivity in the process of climate adaptation planning) is often overlooked (Van Den Berg and Keenan 2019).

One barrier to procedural justice in climate and water planning is top-down decision making and planning, which often prioritizes the perspectives and data from academic or agency scientists and policymakers over the insights and experiences of frontline communities who are most directly impacted by climate issues, thus hindering effective implementation (Fernandez-Bou et al. 2022; United Nations 2024). This can be the result of uneven power dynamics and lack of internalization of equity in public planning processes (Gonzalez 2017). This can also be the result of structures that marginalize or exclude local culture, voices, or agency (McNeeley 2012; McNeeley and Lazrus 2014). For example, lack of respect or disregard for Tribes often occurs in non-Tribally led climate planning (Hasert et al. 2024).

> Effective and transformative water and sanitation management strategies are deeply rooted in local cultures, representative of the communities they serve, and achieved through substantial participation by marginalized groups.

A lack of meaningful representation[21] in climate adaptation planning exacerbates, redistributes, and creates new inequities, compounding existing planning and management challenges (Swanson 2021). Anguelovski and co-authors (2016) conducted a study across eight cities, which included Boston and New Orleans, to examine marginalized groups such as low-income residents, ethnic minorities, and Indigenous populations. The findings revealed that the exclusion of these at-risk groups from urban climate adaptation planning resulted in urban segregation, spatial inequity, widespread displacement of frontline communities, and undesirable land use planning and development interventions (Anguelovski et al. 2016). Furthermore, failure to engage and recognize marginalized groups increases the likelihood that the plans or activities will not be accepted and distrust in local government will increase (Swanson 2021).

The lack of procedural justice in climate planning can also be the result of a process that is nominally inclusive but makes it difficult or impossible for some to participate because of cost or time requirements. Dobbin and Lubell (2021) showed how this was the case for many of the Latino populations in the San Joaquin Valley of California in the regional groundwater planning processes. Even though many people in these communities knew about opportunities for engagement, disadvantaged community (DAC) members struggled to participate due to lack of time, lack of paid staff to attend meetings, and lack of political recognition (Dobbin and Lubell 2021).

Cultural differences and misunderstandings are also significant barriers to equitable and locally accepted climate adaptation planning efforts (McNeeley and Lazrus 2014). McNeeley and Lazrus

21 Meaningful representation is defined here as the active inclusion and recognition of diverse interests, needs, and priorities of frontline communities.

(2014) found that different worldviews can clash because of different ways of perceiving climate risks based on varying cultural interpretations of how nature functions. This can then result in climate adaptation strategies that are less effective when lacking the range of voices and views of those affected by adaptation strategies (McNeeley and Lazrus 2014). For example, conflicting worldviews (e.g., viewing water as a common good versus private property) held by communities who rely on a shared aquifer in south-central Oklahoma that is sensitive to drought resulted in conflict, scrutiny, and distrust of a scientific study that set a maximum allowable yield for the aquifer. This resulted in some community members discounting proposed management strategies. When local communities feel that their cultural views are not respected and incorporated into management decisions, the barriers caused by cultural disconnect are difficult to overcome.[22]

Strategies for centering communities in climate planning across states, cities, and water utilities from the US Water Alliance include: 1) incorporating community considerations into climate vulnerability assessments, 2) including community vulnerability assessments in climate planning, and 3) integrating community-based organizations into climate planning efforts (US Water Alliance 2017). To fully realize the potential of these strategies, it is crucial to bridge the gap between top-down planning by agencies and bottom-up approaches rooted in local communities. One strategy to center frontline communities in management and planning is to begin with a visioning stage. For example, Seattle Public Utilities held a visioning stage for their Shape Our Water project, a 50-year initiative focused on resilience and equity for Seattle's public drainage and wastewater services (US Water Alliance and Water Utility Climate Alliance 2024a). Seattle Public Utilities brought together almost 400 participants from historically underrepresented groups to synthesize community insights and shape project goals, building trust and lasting partnerships while centering equity in their planning for climate resilient sanitation.

Community-based organizations can play a critical role in keeping public planning on track to climate resilience for frontline communities (Gonzalez 2017). Public planning is most successful when community-based groups and leaders are consistently influential in the following areas:

1. **Establishing principles and protocols for community engagement from the outset;**
2. **Developing place-based resilience indicators (see Section 7.6);**
3. **Implementing administration regulations that prioritize community needs; and**
4. **Allocating resources in line with communities' visions (Gonzalez 2017).**

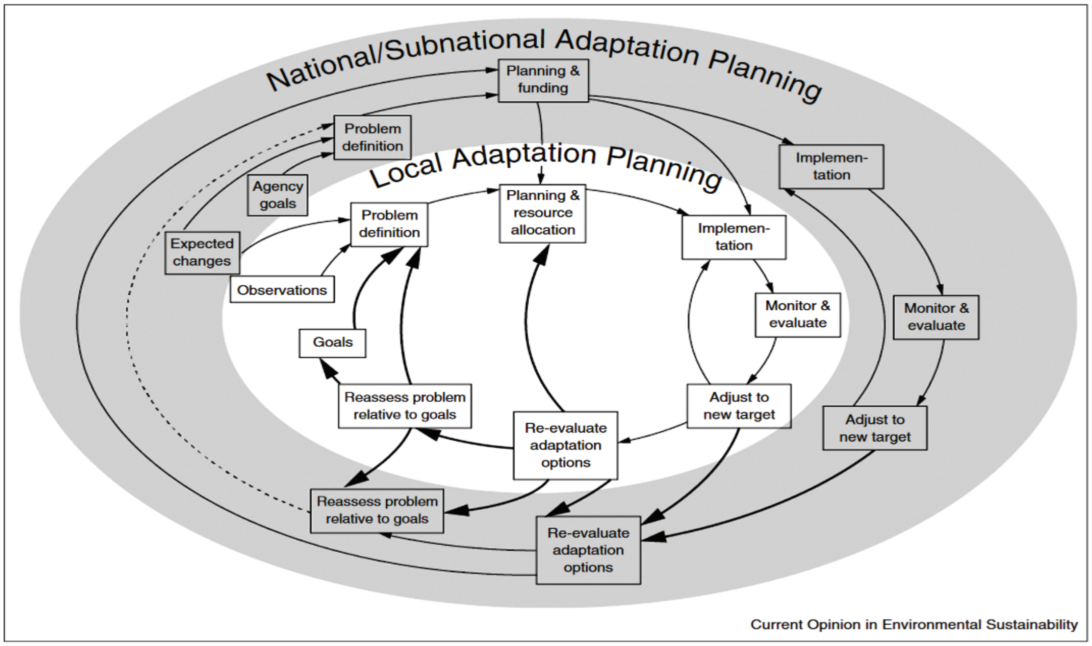
A case in point is the Center for Earth, Energy and Democracy's (CEED) role in influencing equitable and culturally relevant climate adaptation planning in Minneapolis. CEED, a research, education, and action nonprofit, was responsible for incorporating community voices into the Minneapolis Climate Action Plan through an Environmental Justice Working Group that meet with community members and keep planning on track to enhance climate resilience for the city's disproportionately impacted communities (Center for Earth Energy and Democracy 2012; Gonzalez 2017). CEED incorporated

22 A resource to help planners and managers address the unique needs, values, and cultures of Indigenous peoples in climate planning is the Tribal Climate Adaptation Menu. One of the strategies included in the resource is considering cultural practices, which provides tactics to seek guidance from community members on adaptation needs and actions, to respect and build relationships, and to honor cultural responsibility and histories for the benefit of short- and long-term adaptation efforts (Tribal Adaptation Menu Team 2019).

data-driven resilience goals into the plan by using a justice mapping tool and called for monitoring to measure the effectiveness of the plan's strategies in reducing burdens across income-classes, neighborhoods, and races (Gonzalez 2017). As a result, Minneapolis committed to a Green Zone Initiative that seeks to transform areas of the city facing cumulative impacts of environmental, social, and economic vulnerability into healthy neighborhoods through green infrastructure (see Section 6), thus increasing resilience against climate impacts (Gonzalez 2017).

Another empowering top-down and bottom-up planning approach that links frontline communities and agencies in climate adaptation planning involves the use of boundary organizations (Chapin et al. 2016).[23] Chapin and co-authors examined how the Community Partnerships for Self-Reliance, a collaboration of the Alaska Native Science Commission and University of Alaska Fairbanks, connected Alaska Native communities' vision of self-reliance with technical expertise and research. This partnership supported four Indigenous communities (Igiugig, Koyukuk, Newtok, and Nikolai) created community-driven climate adaptation plans based on various goals, including assessing flood risks, sustaining water rights, and more (Chapin et al. 2016). Community Partnerships for Self-Reliance served as a platform to shape adaptation discussions around the four communities' long-term self-reliance goals and facilitated communication between local adaptation planning and state and national organizations, influencing planning decisions at larger scales and across sectors (see Figure 8).

FIGURE 8. Observed Climate Adaptation Networks Between Local Rural Alaskan Communities and National/Subnational Planning Using a Boundary Organization



Observed adaptation-planning network at the national/subnational scale and at the community/local scale in rural Alaska. The dashed arrow is structurally plausible but was not observed during our brief study. Thick arrows indicate pathways strengthened by the CPS partnership.

Source: Reprinted from Current Opinions in Environmental Sustainability, Vol 19, Chapin et al., Community-empowered adaptation for self-reliance, Copyright (2015), with permission from Elsevier.

23 Boundary organizations typically function outside of formal organizational structures, allowing for communication across non-traditional pathways and across different sectors and scales (Guston 2001; Sternlieb et al. 2013; Anderies, Janssen, and Ostrom 2004; Chapin et al. 2016).

The partnership increased the number of climate adaptation options that were specific to their local conditions and cultures and enhanced representation in regional decision making. For example, the Koyukuk Tribal Council lacked flood history documentation to demonstrate the effectiveness of their adaptation strategy to build above the historical flood-line on the riverbank. They worked with the University of Alaska Fairbanks to assemble flood data to attract state and federal funding. Also, Igiugig's Tribal president joined the University of Alaska Fairbank's Alaska Center for Energy and Power advisory committee to advise on renewable energy needs throughout rural Alaska (Chapin et al. 2016).

The partnership between the Wind River Reservation, university partners, and federal agency scientists (mentioned in Section 7.1) to co-develop drought management tools, including the Wind River Reservation Drought Management Plan, is another example of how collaborations with frontline communities can overcome barriers and center local needs, values, and knowledge in water and sanitation planning (McNeeley et al. 2018; McNeeley, n.d.). Frequent drought events have caused devastating social and ecological impacts to the Eastern Shoshone and Northern Arapaho Tribes (McNeeley, n.d.). To provide these Tribes with their own climate data and information for on-reservation drought decision making, government agencies and university partners worked with the Tribes to produce actionable science guided by their priorities (Stiles, Umphlett, and Cottenoir 2020; McNeeley et al. 2018). Before the collaboration, the Tribes faced significant challenges in climate adaptation planning and management, lacking the monitoring and early warning systems needed to assess and declare drought. The collaboration resulted in building the capacity of Tribal water managers with technical expertise and a drought plan grounded in Tribal culture, needs, and knowledge along with the best available science to prepare for and respond to future droughts.

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Equity-centered climate, water, and sanitation projects also require financial resources for community participation (Cochran et al. 2013). Dobbin and Lubell (2021) suggested strategies to support small DAC participation in groundwater planning, including stipends for meeting participation, ongoing support from technical assistance providers, and funding for communities to hire outside experts, if needed. For example, New York State's Energy Research and Development Authority's Paying for Community Expertise program, which is part of their Energy and Climate Equity Strategy. The program provides financial compensation to community-based organizations and individuals from historically marginalized communities affected by climate change to inform clean energy programs that equitably share benefits (New York State Energy Research and Development Authority n.d.). For more information on these kinds of strategies to enhance the capacity for community engagement in water and climate decision making, see Section 10.2.

Centering frontline communities in water and sanitation planning and management fosters equitable and climate-resilient outcomes.

Centering frontline communities in water and sanitation planning and management fosters equitable and climate-resilient outcomes. Effective strategies emphasize the active participation of frontline community members, ensuring that their knowledge, needs, cultural values, and priorities are integral to planning processes. Key approaches include:

1. **Begin with a visioning stage to incorporate frontline communities' insights into climate-resilient water and sanitation planning from the outset;**
2. **Integrate community-based organizations into climate adaptation and water and sanitation planning and management efforts to improve the representation of marginalized groups;**
3. **Foster collaborative research partnerships that act as boundary organizations, connecting frontline communities with regional and national planning efforts while developing locally tailored resources for self-reliance; and**
4. **Provide financial resources, such as stipends, to empower individuals and communities to meaningfully engage in management and planning processes.**

7.3 WATER AND SANITATION PROVIDERS FINANCIALLY SOUND IN THE FACE OF CLIMATE CHANGE

Attribute description: The financial health of utilities and cities is supported by proactive, long-term planning and management strategies that result in accessible, affordable, and climate-resilient water and sanitation for frontline communities.

Water affordability is a fundamental principle of the human right to water and sanitation and perhaps the least studied dimension of household water insecurity (Meehan, Jepson, et al. 2020). The two concepts of utility financial capability and household affordability[24] are distinct, yet the ways in which water and sanitation managers approach long-term planning for financial capability can influence rates, directly affecting household affordability challenges (River Network 2021b). Climate change impacts affect both utility financial capability and affordability of water and sanitation, especially for frontline communities that may already face challenges paying for services (Pacific Institute and DigDeep 2024; Bluefield Research, n.d.; US Water Alliance 2017; River Network 2021b). This attribute focuses on long-term, proactive planning strategies to help ensure utility and city financial stability in the face of climate change with the goal of keeping water and wastewater bills accessible and affordable for households. Later, Section 8.5 focuses on approaches that utilities and other government agencies can use when affordability goals are not met.

> Management and planning tools are available to improve utilities' and local governments' long-term financial capability and water affordability outcomes for households in the face of climate change, including improved asset management, equitable rate structures, and improved demand-forecasting, yet barriers persist.

Climate change is driving more extreme temperatures, droughts, flooding, sea level rise, wildfires, and storms, resulting in damaged infrastructure, the need for additional infrastructure, contaminated source water, and lack of access to water and sanitation (Pacific Institute and DigDeep 2024). This is leading to unprecedented costs for both centralized and decentralized water and sanitation systems. Climate change and associated rising costs are disproportionately affecting utilities and households in frontline communities (Jay et al. 2023; US Water Alliance 2017). Utilities facing significant financial challenges are often smaller in size and primarily serve communities with low-income populations (Teodoro and Thiele 2024). These communities are more likely to have water infrastructure systems that are not "right-sized" for their population (e.g., oversized infrastructure due to population loss), resulting in challenges collecting

24 At the utility scale, financial capability is defined as the ability of the utility to pay for the capital and operations costs associated with providing safe and reliable water and wastewater services (J. P. Davis and Teodoro 2014). At the household scale, affordability refers to water and sanitation costs that are manageable and do not impede household's ability to cover other essential expenses, such as food, housing, and electricity (J. P. Davis and Teodoro 2014; Feinstein 2018; Pacific Institute and Community Water Center 2012, Teodoro 2018; Teodoro and Thiele 2024).

enough revenue to fix increasing issues related to climate change through rates (River Network 2021b). Climate change also increases water treatment costs, which disproportionately impact small, rural water systems (US Department of Agriculture, Rural Community Assistance Partnership 2017). The exorbitant costs of replacing and fixing water and sanitation infrastructure to keep pace with climate change can be passed on to ratepayers via inflated water bills (River Network 2021b; Drugan 2023).

Management and planning tools are available to improve utilities' and local governments' long-term financial capability and water affordability outcomes for households in the face of climate change, including improved asset management, equitable rate structures, and improved demand-forecasting, yet barriers persist (River Network 2021b; Heberger, Donnelly, and Cooley 2016). For example, smaller and economically disadvantaged communities may not have the capacity to make needed improvements, which typically require a significant amount of time and resources (River Network 2021b). Many water systems, especially in rural and underserved communities, often lack sufficient technical, managerial, and financial capacity (Pacific Institute and Community Water Center 2012). As a result, financially strained water and wastewater utilities often make tradeoffs among three primary financial goals: household affordability, utility affordability, and infrastructure investments (Patterson et al. 2020).

> Asset management is an opportunity for utilities to make cost-effective, equitable, and climate-resilient infrastructure investments that target disadvantaged communities experiencing high water costs.

Asset management is an opportunity for utilities to make cost-effective, equitable, and climate-resilient infrastructure investments that target disadvantaged communities experiencing high water costs (River Network 2021b). Asset management is the practice of managing capital assets to the appropriate budget for operation, maintenance and replacement of these assets while delivering optimum service levels (Vedachalam, Male, and Broaddus 2020). As mentioned above, aging, degrading, and oversized infrastructure are a leading cause for unaffordable water rates, and climate change is exacerbating this challenge (River Network 2021b). Embracing asset management planning is a proactive approach to address the impacts of climate change on infrastructure and makes climate planning more manageable and approachable (Lyle, VanBriesen, and Samaras 2023; US EPA, OW 2012).

The Integrated Water Resource Planning (IWRP) model is one asset management framework that incorporates climate resilience that holistically considers a utility's current performance, risks that require preparation (e.g. climate change), conservation strategies, and more to inform projects and investments that maintain supply, reduce costs, and mitigate risks (River Network 2021b). Colorado Springs Utilities' Integrated Water Resources Plan assessed system performance, incorporating climate change, changes in demand, infrastructure issues, and more — all of which affect water supply costs and reliability (Colorado Springs Utilities 2017). This proactive approach paved the way for the city to safeguard long-term water supply and reduce financial strain by mitigating the rising operational and infrastructure costs driven by climate change (Colorado Springs Utilities 2017; River Network 2021b).

Asset management planning can be daunting for small and underresourced water and wastewater utilities, which typically serve low-income populations, making long-term financial capability increasingly important for affordability outcomes (Teodoro and Thiele 2024; River Network 2021b). In its Equitable Water Infrastructure Toolkit, River Network recommends taking interim steps toward comprehensive asset management, including water loss auditing, service sharing, regionalization, and technical assistance (River Network 2021b). Additional asset management resources for small, disadvantaged utilities and communities include:

1. **Rural Community Assistance Partnership's (RCAP)** ***Asset Management Guide for Small Drinking Water and Wastewater Systems*** **(Rural Community Assistance Partnership 2024);**
2. **RCAP's** ***The Basics of Financial Management for Small Community Utilities*** **(Rural Community Assistance Partnership 2022);**
3. **EPA's** ***Asset Management: A Handbook for Small Water Systems*** **(US EPA, OW 2022a);** and
4. **EPA's** Climate Resilience Evaluation and Awareness Tool **(CREAT) (US EPA 2014a).**

Demand forecasting is another important component of long-term planning for water utility financial capability. Demand forecasting is the analysis of future water demands to understand spatial and temporal patterns of future water use to optimize system operations, prepare for future expansions or water purchases, or plan for future revenue and expenditures (Pacific Institute and Community Water Center 2012). Plans that over- or under-estimate future water demand can cost utilities millions of dollars, which can have ripple effects on water rates and affordability (Heberger, Donnelly, and Cooley 2016). Furthermore, demand forecasting that takes climate change into account will help minimize reactive responses to climate impacts, like drought surcharges, which have negative impacts on water affordability for low-income households (Feinstein et al. 2017; Rachunok and Fletcher 2023). The Pacific Institute outlined best practices for demand forecasting in *A Community Guide for Evaluating Future Urban Water Demand,* which included accounting for water conservation and efficiency and climate change and drought (Heberger, Donnelly, and Cooley 2016). Water efficiency and conservation initiatives, like water-saving technologies (see Section 5.2), have reduced per capita water use in the US since the 1980s (Gleick and Cooley 2021). Better water

demand forecasting and planning are essential for preparing for climate change and realizing the cost savings of conservation initiatives (Cooley, Shimabuku, and DeMyers 2022).

Information gathered from these processes is used to set water and wastewater service rates, presenting another important reason for incorporating climate change into asset management and water demand forecasting. Although these tools can help utilities better plan for climate change impacts on the costs of maintaining and operating water and wastewater systems, there may still be times when rates will need to increase to ensure revenue stability, fairness, cost recovery, and affordability (Beecher 2020). Proactive (rather than reactive) approaches to rate setting can support climate-resilient and affordable outcomes for the communities served. For example, many small water systems in California were unable to respond to drought impacts due to rates that remained stagnated for years and even decades (Klasic et al. 2022). This resulted in under-investment in aging infrastructure, which failed during the 2012-2016 drought. The small water systems that revised their rate structure prior to drought were more resilient to the impacts because they were able to generate sufficient revenue to maintain infrastructure and reduce system failures (Klasic et al. 2022). This example shows that proactive rate-setting can help small water systems maintain resilience, ensuring that they can maintain infrastructure and meet community water needs even in the face of climate challenges like drought.

The Portland Water Bureau's (PWB) *Supply System Master Plan* includes asset management, demand forecasting, and rate projections, which all take climate change into account to ensure the continued delivery of high-quality drinking water to customers for generations to come while making smart investments that do not overburden rate payers (Portland Water Bureau 2021). To address the inherent uncertainty in long-term forecasting and planning, PWB incorporated a range of scenarios such as different climate impacts, economic conditions, new regulations, and population growth to develop baseline investment projections over the next 20 years, plus a set of adaptive actions that can be implemented if conditions change. The planning approach has helped PWB to avoid budget surprises and increase its resilience to climate change (Edward Campbell and Heyn 2024).

Climate change is leading to higher costs for acquiring, maintaining, and operating climate-resilient water systems. Although more focus is needed on strategies at the climate-equity nexus, existing approaches to long-term planning and management provide a good starting point to ensure that frontline communities can maintain financial capability and in turn provide affordable water to rate payers in the face of climate change. Key strategies for financial capability are:

1. **Include asset management in long-term planning that takes into consideration climate change impacts to water and wastewater infrastructure;**
2. **Conduct demand forecasting to help ensure that future water demand projections account for both climate change scenarios and efficiency initiatives; and**
3. **Employ proactive rate setting to prevent reactive rate increases that could render water and sanitation services unaffordable for frontline communities.**

Preparing for climate disruptions and disaster recovery is also important for lessening the economic costs of climate change (R. Newman and Noy 2023), which is described in more detail in the next attribute.

7.4 WATER AND SANITATION SYSTEMS PREPARED FOR CLIMATE DISASTERS AND INEQUITABLE IMPACTS

Attribute description: There is regular planning and management for climate disasters and inequitable climate disruptions to water and sanitation systems that include consideration of interdependencies with other sectors and disaster recovery in frontline communities.

Climate preparedness and response plans can improve social infrastructure and leverage local knowledge by addressing inequitable risks, reinforcing support systems, and enhancing readiness for climate-related natural and technological disasters (B. Taylor et al. 2024). As such, equitable and climate-resilient water and sanitation require regular and coordinated planning and management to prepare for climate disruptions and disasters to centralized and decentralized water and sanitation systems. This means focusing on communities that face the highest risks of climate disasters. Under this approach, water and sanitation systems can persist, adapt, and transform in the face of climate change, thereby increasing the resilience of frontline communities (WaterAid, Australian Aid, and Water for Women 2021).

The 2016 National Infrastructure Advisory Council report characterized the water sector as a critical lifeline, essential for supporting businesses and communities in their daily operations and in recovering from disasters (University of New Mexico Southwest Environmental Finance Center 2024). This underscores the importance of maintaining water services and prioritizing their rapid restoration after disruptions. The impacts can be catastrophic when water and wastewater services are lost for an extended period, such as when extreme weather events damage water infrastructure (University of New Mexico Southwest Environmental Finance Center 2024; Pacific Institute and DigDeep 2024). After Hurricane Helene made landfall in September 2024, it brought catastrophic winds and rainfall throughout six Southeastern states, resulting in deadly flooding. Water infrastructure damage in Buncombe County, North Carolina, disrupted services for tens of thousands of residents, affecting a system that serves a total of 275,000 people (Verduzco, Amy, and Seewer 2024).

Equitable and climate-resilient water and sanitation require regular and coordinated planning and management to prepare for climate disruptions and disasters to centralized and decentralized water and sanitation systems.

In addition to jeopardizing critical access to water services, the health impacts of water-related climate disasters can include water-borne diseases, vector-borne diseases, mental health problems, and malnutrition (Lee et al. 2020). Disease outbreaks are more common in areas with poor water and sanitation services, and women, children, elders, and low-income communities tend to be more vulnerable to flooding related-disasters (Alderman, Turner, and Tong 2012; Lee et al. 2020). Moreover, communities that are historically and currently disenfranchised are the most affected when local governments fail to communicate and coordinate effectively across agencies for preventing and responding to disasters (Gonzalez 2017). People of low socioeconomic status are more vulnerable to disasters, suffering greater physical, financial, and social impacts, which can perpetuate cycles of poverty (Hallegatte et al. 2017; Substance Abuse and Mental Health Services Administration 2017).

Water and sanitation systems face barriers to including climate disaster risks and climate disruption into planning and management, with even greater barriers to small and low-income communities (Cross 2001). Small- and medium-sized utilities often lack the skilled staff (see Section 10), necessary tools, technical expertise, and reliable information (see Section 9) required to manage emerging risks effectively (University of New Mexico Southwest Environmental Finance Center 2024). When preparing for, responding to, and recovering from emergencies, rural communities face multiple challenges including, but not limited to, resource and funding limitations, longer response times, transportation barriers, inadequate communication infrastructure, and complex networks of governing structures (Rural Health Information Hub, n.d.; B. Taylor et al. 2024). Often frontline communities, especially rural ones, have to focus on immediate issues and do not have the time or capacity to plan for climate disruptions to water and sanitation system (B. Taylor et al. 2024). For example, small water systems in California, particularly those serving marginalized populations, often lack water shortage contingency plans and resources to address drought-related climate change impacts (Klasic et al. 2022). Klasic and co-authors found that systems in drought-prone areas that built the necessary technical, managerial and/or financial capacity prior to a drought event had an advantage over systems that did not. In general, systems with this level of preparation are the exception rather than the rule.

Small- and medium-sized utilities often lack the skilled staff, necessary tools, technical expertise, and reliable information required to manage emerging risks effectively.

Equitable, climate-resilient planning and management of water and sanitation includes pre-disaster mitigation, risk reduction, and disaster preparedness (Simonson 2022). This process relies on regular monitoring of priority threats through locally led risk analyses that incorporate climate change factors to identify and address both vulnerabilities and strategies (WaterAid, Australian Aid, and Water for Women 2021). As an example, the Philadelphia Water Department and academic partners conducted watershed-scale flood risk assessments in the Darby-Cobbs Watershed in Southwest Pennsylvania, which is prone to climate-related flooding from both increased precipitation and sea level rise and includes the low-lying, predominantly Black neighborhood of Eastwick (US Water Alliance and Water Utility Climate Alliance 2024b; City of Philadelphia 2024). One project developed fluvial-coastal flood models to visualize watershed-scale streamflow, flooding in Eastwick, and building spatial distribution, including demographic information (US Water Alliance and Water Utility Climate Alliance 2024b). The analysis was informed by community input, especially when developing potential adaptation strategies. For example, Eastwick United Community Development Corporation, a local community-based organization, proposed an equitable relocation plan for the most vulnerable residents in Eastwick (US Water Alliance and Water Utility Climate Alliance 2024b). The partnerships involved in this project helped empower community members to participate in flood risk mitigation and climate disruption planning and facilitated broad coordination across the watershed, resulting in equitable and climate-resilient strategies to reduce flood risk for a frontline community (US Water Alliance and Water Utility Climate Alliance 2024b).

Emergency planning that includes redundancy (i.e., additional capacity created intentionally to accommodate disruption, extreme pressures, or surges in demand) and flexibility (i.e., systems can be adapted in response to disturbances) in water and sanitation systems also increases the chance of adapting to shocks and disruptions (Pacific Institute 2021). Water supply redundancy can include source water diversification (see Section 7.1). For example, Tampa Bay Water, which serves numerous census tracts that are disadvantaged, according to the Climate and Economic Justice Screening Tool (CEJST),[25] constructed a desalination plant in 2008 because of increasing vulnerability to groundwater source contamination from saltwater intrusion (US EPA 2016b). Now, the utility meets the region's drinking water needs with a flexible, blended supply of groundwater, surface water, and desalinated seawater (Tampa Bay Water, n.d.). Tampa Bay Water also partnered with the Water Utility Climate Alliance and Florida Water & Climate Alliance to conduct a vulnerability assessment, using National Oceanic and Atmospheric Administration (NOAA) funding, which found that diversifying their source water likely enables the utility to meet anticipated future needs even in a changing climate (US EPA 2016b). This example showcases the importance of incorporating redundancy and flexibility to help ensure that water supplies are resilient to climate disruptions and accessible for frontline communities.

> Many frameworks and toolkits are available to assist water and sanitation systems to plan for climate-related disruptions.

These approaches help ensure that water and sanitation systems are designed to minimize exposure to potential failures from climate hazards and increase equitable adaptation strategies when disruptions do occur. Many frameworks and toolkits are available to assist water and sanitation systems to plan for climate-related disruptions. One such tool is the EPA's Creating Resilient Water Utilities (CRWU) Climate Resilience Evaluation and Awareness Tool (CREAT), which includes five modules to consider climate risks to assets and adaptation strategies to increase resilience of water systems. CRWU also offers regional climate risk and resilience trainings, including trainings for Tribes, which include climate trends and projections, demonstration of climate resilience tools, utility case studies, and details about financing adaptation and resilience infrastructure projects (US EPA, OW 2024g). One such case study showcased how Lafayette Utility System in Louisiana used the CREAT tool to assess climate scenario impacts on infrastructure, including potential future costs, and how those threats pair with current and proposed adaptation measures (US EPA 2022c). Lafayette Utility found through the exercise that the monetized risk reduction benefits could exceed the total cost of their adaptation plan (US EPA 2022c). See Section 7.3 above for more details on how asset management planning that includes climate disruptions can translate into long-term utility financial health and affordability for households.

Additionally, while not solely climate-resilience focused, EPA's Emergency Response for Drinking Water and Wastewater Utilities provides guidance for developing emergency response plans, building hazard resilience, and joining mutual aid networks like the Water/Wastewater Agency Response Networks (WARN) (US EPA 2014b). EPA also has the Tabletop Exercise Tool for Drinking Water and Wastewater Utilities to help utilities facilitate a training exercise to test response and coordination

25 As of January 22, 2025, CEJST is no longer available under the new federal administration.

to different climate disasters (US EPA n.d.). For small water systems, the Rural Community Assistance Program has numerous resources for climate resilience and emergency preparedness.

After a disaster, it is essential for water and sanitation managers to thoughtfully and equitably rebuild (FEMA 2023a). A community-centered approach to equitable climate disruption recovery can be found in resilience hubs. Resilience hubs are community-serving facilities that support residents and coordinate resources before, during, and after disruptions while strengthening community resilience, emergency management, climate change mitigation, and social equity. They foster self-determination and social connection by leveraging trusted, community-managed spaces (Baja 2019). The City of Baltimore has a cross-sector collaborative Community Resiliency Hub Program, made up of service-based community organizations and the Office of Sustainability, Office of Emergency Management, and Department of Health. The program aims to strengthen connections between frontline community organizations and targeted support and resources, ensuring better emergency response and recovery services for underresourced neighborhoods and their most vulnerable residents during climate disasters or emergencies (Baltimore Office of Sustainability 2021). Resilience hubs in Baltimore have acted as cooling centers during heat waves, provided sandbags in flood-prone areas, distributed water bottles, and served as a place for emergency personnel to meet with residents (Brey 2021). Incorporating resilience hubs into city plans is an important strategy to ensure that the physical infrastructure in which the hubs are located is more climate-resilient, as well as to incorporate the support framework into neighborhood climate action plans (Moran and Ramakrishna 2020). Baltimore's resilience hubs are going beyond reactive approaches to climate disruptions to proactive strategies to reduce the burden of climate change on frontline communities, and they are looking to city planning efforts to help them (Brey 2021).

> Resilience hubs are community-serving facilities that support residents and coordinate resources before, during, and after disruptions while strengthening community resilience, emergency management, climate change mitigation, and social equity.

Integrating climate disaster risks into water and sanitation planning is vital for building climate-resilient, equitable systems, especially for frontline communities that are disproportionately impacted by these threats. Strategies to equitably manage and plan for climate disruptions to water and sanitation include:

1. **Develop emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for frontline communities;**
2. **Include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected;**
3. **Incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for frontline communities;**

4. **Participate in trainings and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions; and**
5. **Integrate resilience hubs into climate, water, and sanitation planning and management to strengthen community resilience and social equity after climate disasters.**

The next attribute covers coordinated climate, water, and sanitation planning across sectors, which is critical for comprehensive climate disruption planning and response.

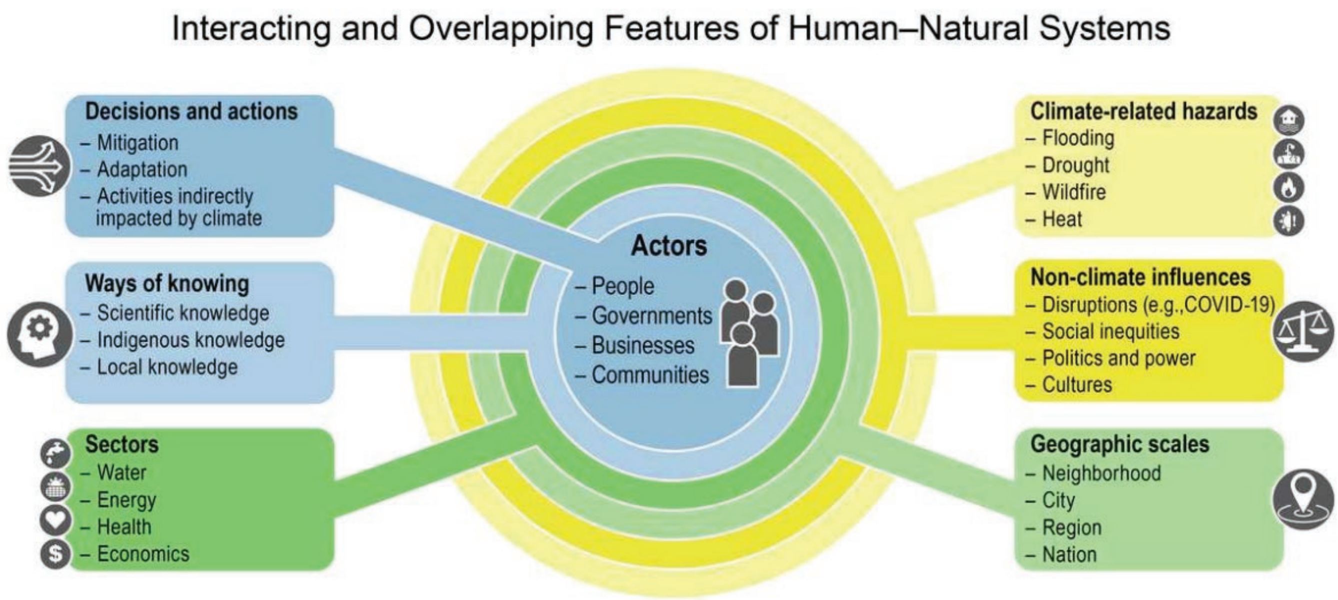
7.5 CROSS-SECTORAL COORDINATION TO ACHIEVE EQUITABLE, CLIMATE-RESILIENT WATER AND SANITATION

Attribute description: Equitable and climate-resilient management and planning efforts are coordinated across sectors, departments, agencies, plans, and different scales of government.

Climate change is affecting, and will continue to affect, frontline communities' access to water and sanitation in countless ways, leading to complex, multi-scalar, and multi-sector challenges that are influenced by unique local geographic and socioeconomic characteristics (Pacific Institute and DigDeep 2024). As such, equitable and climate-resilient water management and planning require coordinating efforts across various plans, departments, agencies, sectors, and scales of government. Water management and planning are connected to multiple sectors — including housing, energy, land use, health, transportation, among others — and these interactions are impacted by both climate-related and non-climate-related influences (Clarke et al. 2018). For example, after Hurricane Harvey struck Houston, Texas in 2017, cascading effects were felt across natural, built, and social systems. Power was lost for 300,000 customers, which disrupted hospitals, communication systems, transportation, water and wastewater treatment plants, and oil refineries (Clarke et al. 2018). Sixty-one communities lost drinking water capability (FEMA 2017). These impacts were complicated by existing non-climate influences like regional land management practices that reduced wetlands, forests, and prairies, lowering Houston's resilience to floods (Clarke et al. 2018).

Interconnections among human and natural systems in a changing climate lead to new risks and can increase existing threats. Figure 9 below, adapted from Brelsford and Jones (2021), highlights six interconnected features of human-natural systems that influence the complexity of systems and the effectiveness of climate mitigation and adaptation actions (Mach et al. 2023). Compounding and cascading interactions among sectors, regions, and hazards further burden already overburdened groups (e.g., rural communities, low-income households, racialized minorities, people with health conditions and disabilities, etc.) (Knighton et al. 2021; Mach et al. 2023; US EPA 2021b).

FIGURE 9. Features Involved in Complex and Connected Human-Natural Systems Shaping Actors' capacity to Respond to Climate Change



Source: K.J. Mach et al. 2023

For example, the intersection of discriminatory housing policies, infrastructure investments that favored wealthier, predominantly White suburbs, and systemic racial and economic inequalities have concentrated low-income, Black, and other marginalized frontline communities in areas with higher flood risks (Bigger and Millington 2020; X. Huang and Wang 2020; Mach et al. 2023; Tate et al. 2021; US Global Change Research Program 2018). These vulnerabilities are further exacerbated by federal flood risk response programs, which privilege wealthier, White communities, providing them with more funding for mitigation and relocation (Mach et al. 2019; US Global Change Research Program 2018). This complex web of interactions leaves frontline communities with fewer resources to respond to flood risks, amplifying the cascading impacts of climate change and deepening racial, economic, and environmental disparities.

To effectively assess the risks associated with climate-related stressors, water and sanitation management and planning are encouraged to consider the interactions among the many systems and sectors and the effects of the complex stressors on water and sanitation systems, especially for frontline communities (Clarke et al. 2018; Mach et al. 2023). Management and planning thus require coordination across multiple scales and sectors to proactively and collaboratively address these nuanced challenges to enhance the resilience of frontline communities to climate impacts, minimize unintended tradeoffs, and ensure access to water and sanitation (United Nations Framework Convention on Climate Change 2014).

The coordination of water and climate management and planning horizontally within one sector and vertically across multiple scales of governance requires careful coordination and strategic alignment. Water management and regulation has historically been siloed, or isolated, and centralized (Mukheibir, Howe, and Gallet 2014). Coordinated approaches to water management, such as Integrated Water Resource Management (IWRM) and the One Water framework, have gained popularity as strategies for addressing complex water challenges. IWRM is a holistic approach that promotes the coordinated development and management of water, land, and resources to maximize social and economic welfare equitably while ensuring ecosystem sustainability (United Nations Environment Programme 2017). One Water builds on IWRM and strives to manage all water in an integrated, inclusive, and sustainable manner (US Water Alliance 2016). The staples of the One Water framework include recognition that all water has intrinsic value, an emphasis on solutions with multiple benefits, a systems approach, watershed-scale thinking and action, right-sized solutions, multi-sector partnerships, and equitable engagement (US Water Alliance 2016). For example, the report *An Equitable Water Future: Pittsburgh* outlines One Water strategies to address Pittsburgh's outdated infrastructure, which struggles with intensified rainfall, frequent sewer overflows, and water quality degradation (US Water Alliance 2021).These climate impacts disproportionately harm low-income neighborhoods and communities of color, where sewer backups may exacerbate air quality issues and asthma rates (Brink, n.d.). Coordinated planning between two distinct agencies, the Pittsburgh Water and Sewer Authority and Allegheny County Sanitary Authority, was recommended in the plan to improve resilience and keep rates affordable for low-income residents (US Water Alliance 2021).

To effectively assess the risks associated with climate-related stressors, water and sanitation management and planning are encouraged to consider the interactions among the many systems and sectors and the effects of the complex stressors on water and sanitation systems, especially for frontline communities

However, integrated water management approaches face barriers. Challenges to achieving integrated planning and management include legislation and regulations, lack of economic tools to value integrated water services, planning and collaboration, culture and capacity, and citizen engagement (Mukheibir, Howe, and Gallet 2014). For example, while developing their IWRM plans and programs, California noted the challenge of moving beyond conceptual integration and coordination, especially for sharing data among agencies (American Water Resources Association Policy Committee 2012). Additionally, the Fifth US National Climate Assessment noted challenges to managing complex, interconnected systems in response to climate change. These challenges include uncertainty in future climate scenarios, competing objectives among actors, broadly distributed knowledge and power, geographically and functionally nested governance systems, and feedback and path dependencies (Mach et al. 2023).

Poor coordination across complex systems in climate adaptation planning and management can have serious consequences. For example, fragmented decision making across the energy-water nexus in the US can lead to increased efficiency in one sector but increased demand in another (Hussey and Pittock 2012). In shifting away from coal toward natural gas, renewable energy, and nuclear energy in the energy sector, an increase in water demand at power facilities can result (Ernst and Preston

2017) When coupled with increasing hot and dry conditions, this can result in less efficient combined water and energy systems (Ernst and Preston 2017). As another example, one of the top barriers to drought decision making in the US is limited coordination or collaboration between jurisdictions and agencies (Beeton and McNeeley 2020). As discussed in Section 7.3, water systems that lacked drought contingency planning were less equipped to maintain financial stability and adapt to the impacts of the 2012–2016 drought, which exacerbated the vulnerability of drinking water, especially for small and rural systems that have limited capacity (Klasic et al. 2022). This highlights the importance of overcoming barriers to coordinated climate and water planning to increase the resilience of water systems, especially for frontline communities.

At the federal level, the 2021 White House Executive Order on Tackling the Climate Crisis at Home and Abroad promoted a government-wide, cross-sector approach to boost resilience by protecting public health, conserving resources, advancing environmental justice, and supporting jobs and economic growth (The White House 2021). The executive order, from the Biden-Harris administration, emphasized coordinated planning with state, local, and Tribal governments, leading to the establishment of the White House Office of Domestic Climate Policy and the National Climate Task Force (The White House 2021). The White House also released the *National Climate Resilience Framework* in 2023, which offered guidance to coordinate an "all-hands-on-deck" effort to build climate resilience in the US at the federal level, including approaches to interagency collaboration and coordination (The White House 2023). For example, the Thriving Communities Network (TCN), an interagency effort established in 2022 to coordinate place-based technical assistance across urban, rural, and Tribal communities, is highlighted as a coordination model to enhance place-based community resilience (The White House 2023; US Department of Transportation 2024a). TCN has helped a range of frontline communities tackle complex climate-related challenges. In one case, TCN helped strengthen state and federal partnerships with the Standing Rock Sioux Tribe to help find opportunities to address housing, health, and infrastructure challenges (US Department of Transportation 2024b).

For coordination to succeed, actors need to be aligned on and in communication about planning efforts to avoid duplicated and fragmented efforts. The roles and responsibilities for the actors must be clearly defined between sectors and departments (e.g., climate change, agriculture, energy, water, etc.), to avoid overlapping responsibilities and lack of accountability.

For coordination to succeed, actors need to be aligned on and in communication about planning efforts to avoid duplicated and fragmented efforts. The roles and responsibilities for the actors must be clearly defined between sectors and departments (e.g., climate change, agriculture, energy, water, etc.), to avoid overlapping responsibilities and lack of accountability (WaterAid, Australian Aid, and Water for Women 2021). Additionally, a functioning inter-departmental coordination mechanism is needed, and climate change vulnerability assessments must be embedded into information exchange and dialogues between sectors (WaterAid, Australian Aid, and Water for Women 2021). For example, the White House's *National Climate Resilience Framework*, recognized this need and included an action to increase coordination and communication across federal agencies, which already separately provide climate services to constituents (The White House 2023). Making these actions work in practice can be challenging due to the many overlapping sectors and features of human-natural systems, as shown in Figure 9 above. The following examples showcase successful management and planning efforts for coordinating climate, water, and sanitation planning across sectors and departments to increase climate resilience, especially for underserved and overburdened communities. (For more information on resources and strategies to build capacity for cross-sector collaboration, see Section 10.3.)

At the state level, an example of a coordinated water planning effort can be found in Colorado's Water Plan, which outlines goals to help Coloradans do more with less water and increase resilience to climate change impacts. First developed in 2015, the plan is a framework for collaborative water planning and established the Water Plan Grants Program in Colorado that funds water projects across sectors, giving preference to those that have multiple benefits, multiple purposes, and involve multiple stakeholders (Colorado Water Conservation Board 2023). The 2023 plan built upon the previous version and has four focus areas, including vibrant communities, robust agriculture, thriving watersheds, and resilient planning (Colorado Water Conservation Board 2023). The Colorado Water Conservation Board (CWCB), maintains and implements the plan through coordination with federal, state, and local partnerships across sectors, including drinking water, wastewater, stormwater, agriculture, energy, forest management, parks, and wildlife. Actions in the plan aim to address themes such as equity, climate resilience, water conservation, land use, education, and more. For example, the plan led to the creation of an interagency environmental justice mapping working group to strengthen certain tools, like the Colorado Department of Public Health and Environment's Colorado EnviroScreen, which identifies communities with the highest environmental risks. The goal is to foster collaboration across agencies to improve mapping tools for water planning and funding, with a focus on supporting and engaging low-income communities and communities of color in building greater resilience (Colorado Water Conservation Board 2023).

Another example of a robust, cross-sector and collaborative planning effort is the Alaska Native Tribal Health Consortium's report, *The Unmet Needs of Environmentally Threatened Alaska Native Villages*, which sought to improve the effectiveness and equity of federal and state support for small, rural Alaska communities to address climate change impacts to infrastructure (Alaska Native Tribal Health Consortium 2024). ANTHC proposed a conceptual Alaska Environmental Threat Mitigation Framework (Mitigation Framework), based on FEMA's National Disaster Recovery Framework, as a coordinated management framework for disaster response. The concept assumes implementation at the state level and includes a detailed description of the roles and responsibilities for administration, risk assessment, planning, and implementation for different sectors such as finance, public health, education, housing, infrastructure, and more. A key component of the proposed Mitigation Framework is the creation of Community Specific Technical Assistance Teams to provide ongoing support to rural Alaska communities for relationship building, amplifying community voices, streamlining access to resources, and delivering technical expertise to inform decision-making through disaster mitigation efforts. This framework is an example of a cross-sector, collaborative, and co-produced approach to planning for climate disruptions that could be adapted and applied in other frontline communities.

In New Jersey, the Camden Collaborative Initiative (CCI) has coordinated and implemented innovative solutions to complex environmental challenges. CCI is a collaboration between the City of Camden, Camden Community Partnership, Camden County Municipal Utilities Authority, New Jersey Department of Environmental Protection, and the US EPA (Camden Collaborative Initiative, n.d.). Formed in 2013, CCI works to maximize limited resources for enhancing public health and quality of life for residents by working across sectors on issues related to sewage flooding, brownfield remediation, air emission reductions, environmental justice, recycling, and illegal dumping (US Water Alliance 2019). Since its formation, CCI has been joined by over 50 environmental and community service nonprofit partners and has been an integral part of implementing Camden's Stormwater Management and Resource Training (SMART) Initiative, which has developed an extensive network of green infrastructure projects to remediate environmental injustice in communities and reduce runoff (US Water Alliance 2019). These projects transform Superfund sites and brownfields into community parks, increasing riverfront access, protecting water quality, supporting economic development and increasing climate resilience for frontline communities (US Water Alliance 2019).

Because of water infrastructure's interdependencies with other infrastructure systems and the risk for cascading impacts, coordination and integrated planning and management across sectors, departments, and agencies are critical for disaster preparedness and recovery planning (see Section 7.4) (University of New Mexico Southwest Environmental Finance Center 2024). The EPA's *Community-Based Water Resilience Guide* provides materials to host a workshop demonstrating the importance of integrating water and wastewater utilities into community emergency preparedness planning (US EPA, OW 2022b). Workshops like these can help water and wastewater utilities assess community-wide preparedness for climate disruptions, leading to more proactive and coordinated planning for climate resilience. The Federal Emergency Management Agency (FEMA) developed the *Inclusion, Diversity, Equity, and Accessibility in Exercises: Considerations and Best Practices Guide* to help workshop and training facilitators incorporate diverse stakeholders and social vulnerability into preparedness and planning exercises (FEMA 2023b).

Because of water infrastructure's interdependencies with other infrastructure systems and the risk for cascading impacts, coordination and integrated planning and management across sectors, departments, and agencies are critical for disaster preparedness and recovery planning.

The integration of coordinated management and planning is essential for building equitable, climate-resilient water and sanitation systems in the US. By dismantling silos and fostering cross-scale and cross-sector collaboration, climate change impacts and historical legacies of inequitable water and sanitation access can be addressed. Strategies to accomplish this include:

1. **Align management and planning structures strategically, using frameworks like Integrated Water Resource Management and One Water as foundations for equitable, resilient practices;**

2. Include interagency working groups in climate, water, and sanitation plans to clarify sector roles in climate disruption response, establish coordinated technical assistance programs for frontline communities, and promote climate resilience and equity;
3. Integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together; and
4. Participate in specialized trainings and exercises to learn how to address climate impacts on frontline communities equitably and collaboratively across sectors.

A key element of effective and equitable climate, water, and sanitation planning and management is monitoring and evaluation, which is discussed in the next attribute.

7.6 EQUITABLE, CLIMATE-RESILIENT PLANNING AND MANAGEMENT CONTINUALLY MONITORED AND EVALUATED FOR EFFECTIVENESS

Attribute description: Managers and planners continually monitor and evaluate water and sanitation to achieve equitable and climate-resilient outcomes for frontline communities.

As the impacts of climate change on water and sanitation become more pronounced, agencies and water utilities are developing climate plans and reevaluating existing practices (US Water Alliance 2017). Key elements in the process of building climate resilience include learning, adapting, and transforming, which require monitoring and evaluation to track and assess progress (ARUP et al. 2019). Monitoring is the "ongoing process of tracking and reviewing activities, their results, and the surrounding context," which can be evaluated to understand progress and recognize where adjustments are needed (Spearman and McGray 2011).

Despite research on climate change adaptation and planning processes (Singh et al. 2020; H. Scott and Moloney 2021), monitoring and evaluation of the actions to reduce vulnerability are less developed (Dupuits et al. 2024; United Nations Framework Convention on Climate Change, Kyoto Protocol, and Paris Agreement 2023; Wasley et al. 2023). Monitoring and evaluation provide critical information for effective climate adaptation on what initiatives work, for whom, why, and in what context, as well as information on unintended consequences (Spearman and McGray 2011; United Nations Development Program 2023; Biagini et al. 2014; United Nations Children's Fund and Global Water Partnership 2017). In climate, water, and sanitation planning, sector performance monitoring enables tracking progress, guiding strategic investments and informing new plans and strategies (WaterAid, Australian Aid, and Water for Women 2021). Monitoring and evaluation thus play an iterative role in assessing the effectiveness and equity of climate, water, and sanitation plans and programs as well as informing new plans and strategies.

One of the major challenges in adaptation planning is creating reliable methods to assess the progress and effectiveness of implemented interventions (Olazabal et al. 2019). Fewer than one-third of large US cities with climate action plans incorporate measurable indicators[26] to assess their progress in achieving equity-related goals (Caggiano et al. 2023). As a result, even those plans that address equity considerations often fall short of offering specific recommendations or metrics to effectively advance climate adaptation in the communities with the most need (US Water Alliance 2017).

Another barrier to including monitoring and evaluation in climate adaptation planning and management is the challenge of measuring resilience. Cutter highlighted how the landscape of resilience indicators is “messy and increasingly hard to navigate” due to the vagueness of the term resilience as well as the many motivations and goals for measuring it (Cutter 2016). The multiple framings of adaptation effectiveness can privilege specific adaptation outcomes and create winners and losers. For example, utilitarian and traditional approaches tend to favor cost effectiveness, while justice-centric approaches favor inclusion and agency (Singh et al. 2020).

Monitoring and evaluation can also be challenging due to a lack of baseline data on social and environmental trends and the uncertainties and shifting baselines of climate conditions and hazards (United Nations Framework Convention on Climate Change, Kyoto Protocol, and Paris Agreement 2023; United Nations Children’s Fund and Global Water Partnership 2017). The time between interventions and measurable impacts can be long, causing further complications in planning and implementing monitoring and evaluation initiatives (Pringle 2011). Monitoring and evaluation seek to understand the attribution of changes or outcomes to a specific action, yet climate change and human-environment systems are complex and span multiple sectors and scales, making attribution challenging (United Nations Children’s Fund and Global Water Partnership 2017). Yet another challenge involves hard-to-measure social elements like public trust, the feeling of belonging or inclusion, and capacity building — all of which play a role in how communities engage in adaptation (International Institute for Sustainable Development 2019; United Nations Children’s Fund and Global Water Partnership 2017).

Fewer than one-third of large US cities with climate action plans incorporate measurable indicators to assess their progress in achieving equity-related goals.

In addition to these barriers to adequately monitoring and evaluating climate adaptation, small and rural systems have limited resources and technology for implementing existing monitoring and evaluation frameworks (Howard et al. 2021). The communities most vulnerable to climate change impacts tend to lack sufficient and equitable access to funding (see Section 8), making all components of adaptation planning more challenging (Wasley et al. 2023).

Table 9 includes recommended strategies for overcoming barriers to monitoring and evaluation of adaptation efforts. While monitoring and evaluation efforts are less developed in adaptation

26 Indicators are used to help evaluate progress towards specific objectives and can measure different elements including activities, outputs, and outcomes. Indicators can be either qualitative or quantitative and are useful for making data’s significance more apparent and simplifying complex information (United Nations Children’s Fund and Global Water Partnership 2017).

planning and implementation, examples are provided below to showcase what it can look like in practice to increase climate resilience and equity.

TABLE 9. Strategies and Approaches to Overcome Barriers to Equitable, Climate-Resilient Monitoring and Evaluation

BARRIER	STRATEGY/APPROACH
Lack of monitoring and evaluation focused on equity	• Include frontline communities when developing monitoring and evaluation systems to ensure sustainability in the long run (Dupuits et al. 2024). • Community members are encouraged to be involved in monitoring and evaluation to help develop metrics and processes (Fang et al. 2022). • Identify and establish transparent equity indicators (e.g., income, race, vulnerability, gender, etc.) (Caggiano et al. 2023). • Track distribution of funding and investments after adaptation implementation across racial groups and neighborhoods (Fang et al. 2022). • Memorandums of understanding can help formalize monitoring and evaluation and encourage accountability (Fang et al. 2022). • Community partnerships (e.g., with community-based organizations) can help measure community resilience through interviews, surveys, and focus groups (Fang et al. 2022).
Shifting baselines and uncertainty	• Establish baselines prior to interventions to track what has changed (Pringle 2011). • Data on climate trends and the occurrence of extreme events and disasters are necessary to interpret monitoring results within the context of climate risks (United Nations Children’s Fund and Global Water Partnership 2017). • Flexible interventions that can produce desired outcomes in a range of possible future scenarios are encouraged (Pringle 2011).
Long timescales	• View adaptation as iterative and ongoing, retain flexibility, ensure regular monitoring and evaluation is in place (Pringle 2011).
Attribution	• Use appropriate indicators, including both qualitative and quantitative indicators (United Nations Children’s Fund and Global Water Partnership 2017). • Think in terms of contribution rather than attribution (Pringle 2011).
Lack of resources (funding, technology, etc.)	• Include budget items for monitoring and evaluation in plans (Olazabal et al. 2017). • Collaboration between communities, cities, and other levels of government to create new frameworks of monitoring and evaluation that are feasible for the local context (Caggiano et al. 2023).

The Center for Earth, Energy and Democracy’s (CEED) influential role in centering community members in Minneapolis’ climate action plan, described in Section 7.2, resulted in the plan including protections for Indigenous, low-income, and communities of color (Center for Earth Energy and Democracy 2015). Monitoring and evaluation recommendations for the plan’s actions were provided by the Environmental Justice Working Group, facilitated by CEED. The plan includes an implementation goal to monitor progress annually and to revisit goals and strategies at least every three years. In addition to tracking community-wide greenhouse gas emissions, the plan includes a high-level goal to include equity indicators to measure whether the plan’s strategies, investments, and emission reductions are experienced equitably across neighborhoods, races, and income classes (Minneapolis City Coordinator 2013). CEED is continuing to support the monitoring of the plan’s initiatives, such as monitoring how the city engages with communities, how data and information are collected and used, and how equity is defined and monitored (Gonzalez 2017). While there are limited tangible outcomes to report from this effort, this showcases the importance of community-based organizations in monitoring and evaluating equitable and climate-resilient outcomes from planning efforts.

The collaborative *Climate Change Vulnerability Assessment and Adaptation Plan* by the Bois Forte Band of Chippewa, Fond du Lac Band of Lake Superior Chippewa, Grand Portage Band of Lake Superior Chippewa, and 1854 Treaty Authority features a comprehensive monitoring and evaluation framework, in addition to serving as an exemplary model of cross-sector coordination (see Section 7.5). The goal was to investigate how climate change is currently and could continue to impact the landscape and species within the 1854 Ceded Territory[27] and to identify actions to create more climate-resilient systems. For each key focus area (e.g., air quality, aquatic and terrestrial plants, culturally significant places, etc.), the plan includes multiple strategies to monitor and assess conditions. For example, to address climate impacts on water quality, the plan includes actions to monitor fish mercury concentrations to determine trends and inform consumption guidance, because long-term fish tissue data suggests climate change may be increasing mercury concentrations in regularly consumed fish species (Stults et al. 2016). This plan provides water managers and planners with a good example of incorporating robust monitoring and evaluation actions to ensure culturally important resources and landscapes are resilient to the impacts of climate change.

While there are limited tangible outcomes to report from this effort, this showcases the importance of community-based organizations in monitoring and evaluating equitable and climate-resilient outcomes from planning efforts.

Dallas's *Comprehensive Environmental and Climate Action Plan* is another example of including an outline for monitoring and evaluation, especially focused on equity. The plan details over 90 actions, and for each action there are potential output metrics (City of Dallas 2020). For example, one action pertains to using FEMA's Community Rating System to educate and protect communities from flooding. A metric to monitor and evaluate the outcomes of this action is assessing the number of protected structures in frontline communities (City of Dallas 2020). Additional equity-focused metrics include the number of resilience hubs constructed in frontline communities and the level of financial assistance provided in low-income communities for drought-tolerant landscaping to reduce irrigation water use (City of Dallas 2020). This plan offers water and sanitation managers a practical example of how to choose indicators to monitor and evaluate the equity of their strategies, ensuring that frontline communities become more resilient to climate impacts after strategies are implemented.

27 The 1854 Ceded Territory is 5.5 million acres of ceded land in which the 1854 Treaty Authority, an inter-Tribal natural resource management organization, protects and implements off-reservation hunting, fishing, and gathering rights (1854 Treaty Authority 2017).

Incorporating robust monitoring and evaluation of both new plans and existing operations and programs is essential for water and wastewater utilities, which act as anchor institutions by providing critical services and maintaining trusted relationships within their communities (US EPA, OW 2021). Through these practices, utilities can focus on equity, trust-building, and accountability, all vital for addressing systemic inequities in water and sanitation access. A relevant example, although not directly related to climate adaptation, is the Greater Cincinnati Water Works (GCWW), a utility responsible for water, stormwater, and wastewater services. GCWW monitors data to assess how its practices impact community equity. After examining data on water shutoffs, the utility found they were disproportionately affecting predominantly Black neighborhoods due to a policy requiring residents to pay delinquent bills in full. Recognizing this unintended disparity, GCWW changed its policy and engaged directly with customers to offer affordable payment options, helping them defer or avoid shutoffs (US EPA, OW 2021).

Another avenue for equitably monitoring and evaluating the impacts of climate, water, and sanitation planning on frontline communities can be found in community-led initiatives like the EPA's Urban Waters Program, which funded a citizen science program in the Valle de Oro Refuge, an urban refuge in the South Valley, an unincorporated area outside Albuquerque. The population of South Valley is 82% Hispanic or Latino and the poverty rate is 21% (US Census Bureau, n.d.).[28] South Valley communities have been subjected to racist policies that have impacted their health and welfare. The community faces multiple environmental and health challenges due to air and water contamination from industries, two Superfund sites, and the state's largest wastewater treatment plant (US Water Alliance 2017; Ikenson 2023). Water quality in the acequias, networks of irrigation ditches supporting Indigenous agriculture in the region for centuries, has been negatively impacted (Ikenson 2023). Additionally, long-term drought is intensifying existing water and air quality challenges (US EPA, OW 2014). The Urban Waters Program, led by local community-based organizations, trained students from local schools to collect water samples that provided baseline water quality data for local agencies and supports restoration projects and the development of the urban refuge, which is the nation's first federal public land with a strategic plan aimed at addressing both environmental and economic injustice (Ikenson 2023; US EPA, OW 2014; US Water Alliance 2017). This example showcases how communities can play an integral role in monitoring water conditions and collecting data, which can be beneficial when planning for and implementing monitoring and evaluation, especially in frontline communities experiencing climate change impacts. This approach also provides an educational opportunity for students to better understand environmental justice issues, increasing local knowledge.

> Incorporating robust monitoring and evaluation of both new plans and existing operations and programs is essential for water and wastewater utilities, which act as anchor institutions by providing critical services and maintaining trusted relationships within their communities.

28 Some of the communities in the South Valley, like Mountain View, identify as predominately Chicano (Ikenson 2023).

Toolkits and guidelines exist to help planners and managers at different levels develop locally appropriate, equitable, and inclusive monitoring and evaluation programs for climate resilience. For example, Great Lakes Integrated Sciences and Assessments' Adaptation Monitoring and Evaluation Toolkit includes strategies and resources on preparing for, conducting, and incorporating stakeholders in adaptation evaluation. The toolkit provides guidance on developing an evaluation approach that is culturally responsive and rooted in the principles of cultural competence. Additionally, UNICEF and the Global Water Partnership developed the technical brief *Monitoring and Evaluation for Climate Resilient WASH*, which offers monitoring and evaluation guidance specific to climate-resilient water and sanitation systems (United Nations Children's Fund and Global Water Partnership 2017). The resource goes into detail on selecting indicators to measure climate-resilient water and sanitation, including an extensive list of potential indicators for various actions and desired outcomes. Table 10 is a subset of the indicators provided in the brief.

TABLE 10. Example Indicators Suggested in Monitoring and Evaluation for Climate Resilient WASH

OUTCOME/OUTPUT/ACTIVITY	SUGGESTED INDICATORS
Climate risk informed the development of policies, strategies, plans, and programs	• Do policies, plans, and strategies target frontline populations to improve water and sanitation climate resilience? • Are there legal frameworks that integrate water and sanitation and climate resilience?
Knowledge of climate risks generated and shared	• Do national water and sanitation related departments understand climate risks and how to best respond? • Is understanding of climate risks shared among experts and stakeholders?
Adequate budget and resources allocated	• Is the total value of investment to build water and sanitation resilience sufficient to meet the needs of the frontline populations?
Resilience of technology types understood	• Percentage of water supply and sanitation technologies screened according to their suitability to withstand climate-related shocks and stresses.

Source: Excerpted from United Nations Children's Fund and Global Water Partnership 2017

Incorporating monitoring and evaluation into both climate planning and existing operations is crucial for ensuring equitable water and sanitation access, particularly for frontline communities. Key strategies for equitable monitoring and evaluation frameworks are:

1. Involve community members and community-based organizations in the design and implementation of monitoring frameworks to promote inclusive, attainable, and locally informed processes;
2. Allocate a specific budget for monitoring and evaluation when designing programs and plans to ensure that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives;
3. Use equity-focused indicators to track climate resilience outcomes of water and sanitation plans and programs effectively across communities; and
4. Apply monitoring and evaluation to both new initiatives and existing practices to comprehensively address systemic inequities and enhance accountability.

The management and planning strategies outlined in this section are important for enhancing the climate resilience of frontline communities. Protecting the source water for overburdened and underserved communities is critical as these communities face historical challenges to access drinking water and sanitation that are now exacerbated by climate change. Actively engaging frontline communities helps to ensure that their needs, cultures, and priorities are centered in planning processes and management frameworks. Water and sanitation providers can implement strategies like asset management, proactive rate setting, and demand forecasting to maintain financial stability and provide affordable services for low-income populations in the face of climate change. Additionally, integrating disaster preparedness into planning is key, and incorporating community input helps to identify vulnerabilities and design adaptive strategies tailored to communities' needs. Cross-sector coordination dismantles silos and fosters collaboration among stakeholders, enhancing the effectiveness and climate-resilient outcomes of water and sanitation plans and initiatives. Finally, embedding monitoring and evaluation frameworks within climate, water, and sanitation strategies promotes accountability and transparency and tracks progress toward equitable water access, ultimately improving resilience for frontline communities.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8. Funding and Financing

This category of attributes describes adequate, sustainable, equitable funding, financing, and disaster insurance strategies for frontline communities to build, adapt, maintain, and restore climate-resilient water and sanitation systems.

Equitable, climate-resilient water and sanitation systems for frontline communities require funding to prepare for and recover from climate change disruptions. In the US, spending on water and wastewater infrastructure from local, state, and federal levels was projected to be $179 billion in 2024, which is $91 billion short of the estimated need of $270 billion (US Water Alliance, American Society of Civil Engineers, and EBP 2024). Accounting for outstanding insurance claims from disaster recovery, such as from Hurricanes Helene and Milton, and the need for funding for decentralized systems to build climate resilience would increase this $91 billion shortfall considerably. In some highly disaster-prone areas like Florida and the Gulf Coast, disaster insurance is becoming increasingly unaffordable and even non-existent in some places (Flavelle, Cowan, and Penn 2023).

A critical challenge to building climate-resilient water and sanitation for frontline communities is the inequitable distribution of and access to funding, financing, and insurance options (Wasley et al. 2023). Frontline communities face barriers in accessing these resources because of capacity limitations (see Section 10), systemic racism, legal and regulatory challenges, lack of sufficient local revenue base, unrealistic match requirements, burdensome repayment requirements, and general lack of sufficient funding for climate resilience and adaptation (Frank 2022; Hansen et al. 2021; Hasert et al. 2024; Headwaters Economics 2021; Smith 2023b; Status of Tribes and Climate Change Working Group 2021).

A critical challenge to building climate-resilient water and sanitation for frontline communities is the inequitable distribution of and access to funding, financing, and insurance options.

For households where decentralized water and wastewater are the only viable service solutions, costs often fall entirely on the homeowner for installation, maintenance, and repairs (Calabretta, Cunningham, and Vedachalam 2022; Gibson et al. 2020). Climate change will also exacerbate funding challenges to maintain onsite water and sanitation systems in the face of flooding, sea level rise, water table changes, wildfires, and unpredictable precipitation patterns that contribute to the failure of drinking water wells, septic systems, and other onsite systems (Calabretta, Cunningham, and Vedachalam 2022).

This section describes barriers, strategies, and opportunities for acquiring funding and financing for equitable, climate-resilient water and sanitation for frontline communities. We highlight some of the funding and financing programs relevant to climate-resilient water and sanitation systems from federal sources and, to a lesser degree, examples from states and other sources such as private grants or utility revenue. Other sources are referenced that maintain more comprehensive and up-to-date databases of funding and financing resources. This funding and financing section (and report as a whole) was written in 2024, and as this report was being prepared for publication in January 2025, the administrative change in the White House abruptly paused or rescinded many of the federal funding and programs we discuss herein. Some federal resources and funding mechanisms became either temporarily or permanently unavailable, and their future uncertain. The changes and ongoing uncertainty in federal funding and programs create additional challenges for frontline communities pursuing financial support for efforts to build climate-resilient water and sanitation systems. Wherever possible, archived versions of websites and documents have been provided, although additional resources may become unavailable after this report is published.

In this section, we present five attributes of adequate funding and financing for achieving equitable, climate-resilient water and sanitation in frontline communities:

1. **Funding and financing for climate-resilient water and sanitation infrastructure;**
2. **Funding and assistance for climate-resilient O&M;**
3. **Funding and financing for climate disaster preparedness, response, and restoration of water and sanitation;**
4. **Funding and financing for alternative approaches to equitable, climate-resilient water and sanitation; and**
5. **Affordable climate-resilient water and sanitation for households.**

8.1 FUNDING AND FINANCING FOR CLIMATE-RESILIENT WATER AND SANITATION INFRASTRUCTURE

Attribute description: Climate-resilient infrastructure projects for water and sanitation systems serving frontline communities and households can obtain and sustain funding or financing for planning and infrastructure.

Designing, constructing, and adapting climate-resilient water and sanitation infrastructure for frontline communities and households requires adequate funding. These funds are needed prior to and in anticipation of climate impacts. Ensuring sufficient funding for communities requires addressing the inequitable distribution and access to funding and financing that historically have hindered frontline communities from pursuing climate change adaptation (Wasley et al. 2023). The funding or financing for climate-resilient design, construction, and adaptation also must be sustainable, meaning that the communities and/or households that use them are not burdened by the cost of repaying loans or matching requirements from grants such that they cannot afford the ongoing O&M or other basic needs like health care and food.

Funding for climate resilience and adaptation of water and sanitation infrastructure can come from several sources, including public or private grants, utility revenue, taxes, or other types of government fees. Financing can come from public or private loans (no-interest, low-interest, and other types of loans) and bond funds that must be paid back over time. Here we focus on funding and financing from grants and loans primarily from federal agencies, with some examples from state governments, utilities, and local or regional nonprofit organizations. Water and sanitation systems commonly access loans for construction from private lenders with new opportunities for the water sector arising from "green banks" (see below). Funding and financing through grants and loans are often discussed in tandem because many government funding programs offer both.

> Failure to address the basic capital needs of water and sanitation systems in the US will leave frontline communities at risk of unsafe, unreliable, and unaffordable water and sanitation, especially as climate change increases the risk of climate disasters like hurricanes, floods, droughts, and wildfires.

Failure to address the basic capital needs of water and sanitation systems in the US will leave frontline communities at risk of unsafe, unreliable, and unaffordable water and sanitation, especially as climate change increases the risk of climate disasters like hurricanes, floods, droughts, and wildfires (Pacific Institute and DigDeep 2024). Failure to meet these basic needs also has consequences for the broader economy. Economy-wide losses in personal income, labor income, and disposable income due to underinvestment in water and wastewater infrastructure were estimated at $4.067 trillion by 2043 (US Water Alliance, American Society of Civil Engineers, and EBP 2024). The economy loses $8.58 billion every year that we fail to close the water access gap and provide running water and indoor plumbing for the millions of people in the US that currently lack it (DigDeep 2022). In addition, climate change is increasing the number of billion-dollar disasters each year in the US (Jay et al. 2023). For example, 2023 had the highest number of billion-dollar disasters to date in the US, with 28 weather and climate disasters recorded by the NOAA's National Centers for Environmental Information (A. Smith 2024).

In *Draining: The Economic Impact of America's Hidden Water Crisis* the authors found that the benefits of providing all households in the US with running water and indoor plumbing would outweigh the costs by nearly five to one (DigDeep 2022). These benefits would come from lowered health care costs, more time for work or school, and reducing premature deaths. The US Water Alliance et al. (2024) estimated that by continuing to invest at the spending levels established by the recent surge in water sector spending from the Bipartisan Infrastructure Law (BIL) of 2021 (discussed further below), the US would achieve cumulative savings of $6,745 per household over the next two decades. Climate resilience and adaptation also have a positive cost-benefit ratio. Globally, investing $1.8 trillion from 2020 to 2030 in adaptation efforts like strengthening early warning systems, making new infrastructure resilient, and making water resources management more resilient would achieve an estimated $7.1 trillion in net benefits (Global Commission on Adaptation and World Resources Institute 2019).

The cost of inaction will be substantially greater than the costs of proactively adapting water and sanitation systems to climate change. In the US, research found that communities will save $7 in economic costs after a climate event for every $1 of investment in resilience and disaster preparedness (US Chamber of Commerce, Allstate, and US Chamber of Commerce Foundation 2024). In Alaska, proactive adaptation for publicly owned infrastructure like roads and buildings would reduce expenditures by $1.9 billion to $2.6 billion across two different climate projections (RCP 4.5 and RCP 8.5, respectively) compared with no proactive adaptation (Melvin et al. 2017).[29] Research across other geographies in the US have produced similar results (Neumann et al. 2021).

There are numerous federal and state government funding and financing programs that may be used for climate-resilient design, construction, and adaptation of water and sanitation systems. Three online resources for finding climate adaptation and resilience funding for water and sanitation infrastructure include the River Network's 2021 Equitable Water Infrastructure Toolkit, The American Society of Adaptation Professional's 2022 Ready-to-Fund-Resilience Toolkit, and specific for Tribes, the *Universal Access to Clean Water for Tribal Communities' Bipartisan Infrastructure Law and Inflation Reduction Act Funding Handbook* (American Society of Adaptation Professionals and Climate Resilience Consulting 2022; River Network 2021c; Universal Access to Clean Water for Tribal Communities 2024).[30]

The Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL), was signed into law on November 15, 2021. The law made the largest investment in infrastructure in a generation with a total of $1.2 trillion for rebuilding and replacing failing, aging, and outdated water, energy, transportation, and communications systems (Gleick, Bielawski, and Cooley 2021; US EPA 2024d). The BIL offered approximately $82.5 billion for water-related climate resilience in the form of funding and financing for water efficiency and conservation, alternative water supplies such as water reuse and recycling, safe and clean water projects, nature-based solutions like ecosystem restoration, drought programs, and support for science and data related to climate and hydrology (Gleick, Bielawski, and Cooley 2021). The BIL made more than $13 billion specifically available for use by Tribal communities (Bureau of Indian Affairs, n.d.-a). Most BIL funding will be implemented from fiscal year 2022 through 2026.[31]

The cost of inaction will be substantially greater than the costs of proactively adapting water and sanitation systems to climate change.

29 "RCP" stands for Representative Concentration Pathway and the two numbers, 4.5 and 8.5, are two climate projections used for the Fourth National Climate Assessment to explore greenhouse gas emissions scenarios; 4.5 is the lower scenario and 8.5 is the higher scenario.

30 Following changes made by the new administration in January 2025, federal funding from recent laws has been paused and there remains uncertainty in future availability of funds from these laws.

31 As stated above, the changes made by the new administration in January 2025 paused the use of BIL funds and there remains uncertainty in the future availability of funds from the BIL.

There are already dozens of examples of equitable, climate-resilient water and sanitation projects that have received funding (US EPA, OW 2024d). In Southeast Alaska, the Native Village of Angoon received approximately $1.6 million in BIL funding in 2022 through the Indian Health Service (IHS) Division of Sanitation Facilities Construction (DSFC) Projects funding program to replace a well and rehabilitate its intake structure to allow the water pumps to adjust to low rainfall and changing lake conditions due to climate change (Indian Health Service 2024).[32]

Funding from the BIL helped to build climate resilience in Colusa, California where drought intensified by climate change has made water supplies unreliable. The community, designated as "disadvantaged" by the State of California, received $3.3 million from BIL to install water meters, replace old and asbestos cement pipes, install fire hydrants, properly eliminate access to two contaminated wells, and other activities to protect drinking water supplies and improve conservation (US EPA, OW 2024d). The City of Meriden, Connecticut, received $6 million in BIL funding to address the risks from increasingly intense wet weather events caused by climate change for a retrofit of its wastewater system, which can't handle the volume of water it is now experiencing, leading to raw sewage overflows into local waterways (US EPA, OW 2024d).

Tribes and Tribal communities were targeted benefactors of funding from the BIL (The White House 2022b). Altogether, the BIL allocated $3.5 billion to the IHS Sanitation Facilities Construction Program and another $3.9 billion for water and sanitation programs through other agencies (US Department of Health and Human Services 2022; The White House 2022a). About $200 million of this funding was sent to the Bureau of Indian Affairs (BIA) for the long-standing Tribal Community Resilience Annual Awards Program that has been used to design, build, and relocate climate-resilient water and sanitation systems (The White House 2022b). The types of projects that can be funded by the Tribal Community Resilience Annual Awards Program include trainings and workshops, adaptation planning (and travel support for planning), ocean and coastal management (and travel support for management), capacity building, relocation, managed retreat and protect-in-place planning and implementation, coordination, internships, youth engagement, and implementation of climate adaptation strategies (Bureau of Indian Affairs 2022).

In one example of a climate-resilience project funded by this program just prior to infusion from the BIL, the Lower Brule Sioux Tribe received an award of $195,055 to develop a Drought Vulnerability Assessment and Drought Adaptation Plan (Bureau of Indian Affairs 2022). The Lower Brule Sioux Tribe on the Lower Brule Reservation in South Dakota along the western bank of the Missouri River faces challenges with managing water resources due to drought exacerbated by climate change. These funds enable a first step in performing a drought vulnerability assessment, assessing past drought occurrences, identifying drought impacts on water resources on the reservation, and identifying the capacity of the Tribe to handle future droughts (Bureau of Indian Affairs 2022). The assessment will also identify drought response actions and mitigation strategies based on the vulnerabilities.

32 In January 2025, the Biden-Harris Administration announced $700 million from the BIL for IHS funding programs in Fiscal Year 2025 (October 1, 2024-September 30, 2025) (Assistant Secretary for Public Affairs 2025).

The Dry Creek Rancheria Band of Pomo Indians received almost $1,987,000 through the Tribal Community Resilience Annual Awards Program to pursue a flood-managed aquifer recharge pilot project in California (Bureau of Indian Affairs 2022). The Tribe identified this flood-managed aquifer recharge project in their 2016 climate adaptation plan; the project seeks to restore connection to the floodplain and manage captured high-flow (i.e. flood) water for groundwater recharge and stream flow. The aquifer recharge will support rancheria[33] properties that the Dry Creek Rancheria Band of Pomo Indians own along the Russian River, which is a region with high susceptibility to intense droughts and floods (Grantham 2018; Bureau of Indian Affairs 2022).

Despite the historic funding opportunity presented by the BIL for climate-resilient water and sanitation projects, frontline communities continue to face barriers and challenges in accessing and using federal funding. In *The Unmet Needs of Environmentally Threatened Alaska Native Villages* (Alaska Native Tribal Health Consortium 2024), the Alaska Native Tribal Health Consortium observed the primary barriers to accessing resources and services for addressing environmental threats in Alaska Native communities, such as:

1. **Unclear federal leadership (i.e., lack of alignment of mission responsibility);**
2. **Insufficient federal funding due to inequitable program design;**
3. **Difficulty navigating the myriad objectives, processes, and limitations of various federal competitive grant programs; and**
4. **Coordination of piecemeal and ad hoc federal funding into a coherent response is slow and increases the total cost of the solution.**

While derived from the specific experiences of Alaska Native communities, these observations correspond directly to barriers and challenges observed broadly by frontline communities, their supporters, and other researchers from across the US (Pipa and Geismar 2020; Smith 2023b; B. Taylor et al. 2024; Universal Access to Clean Water for Tribal Communities 2024; US EPA 2021c; US GAO 2020; Vedachalam, Male, and Broaddus 2020).

Other critiques of federal funding programs for frontline communities to build climate resilience and adapt water infrastructure assert that:

1. **They are outdated, fragmented, and incoherent for rural communities in particular (Pipa and Geismar 2020);**
2. **They fail to require the consideration of climate resilience in water infrastructure funding programs (US GAO 2020);**
3. **They do not fund time needed to inventory assets of water and sanitation systems (B. Taylor et al. 2024);**
4. **They focus too much on loans and lack grant funding for capital improvement (Vedachalam, Male, and Broaddus 2020);**

33 A rancheria is a small tract of land that was purchased with federal congressional funds in the early 20th century for Indian Tribes in California that had become homeless due to westward migration during the 19th century gold rush, federal and state efforts to exterminate the Indigenous populations, and the State of California's refusal to ratify treaties with the Tribes (Bureau of Indian Affairs, n.d.-b).

5. **The eligibility requirements block access to small systems with poor financial records and low operating budgets (Vedachalam, Male, and Broaddus 2020);**
6. **Federal match requirements are unfeasible for water and sanitation systems serving small communities with fewer taxpayers (Smith 2023b);**
7. **The processes to apply for and receive funding are neither consistent nor well integrated (Universal Access to Clean Water for Tribal Communities 2024); and**
8. **It is challenging to navigate steps necessary to match funding opportunities with project needs (Universal Access to Clean Water for Tribal Communities 2024).**

Tribal communities often face unique barriers to accessing and using federal and state funding for climate adaptation and resilience (Cozzetto, Cooley, and Taylor 2021; Hasert et al. 2024; Universal Access to Clean Water for Tribal Communities 2024). One of the challenges is that most federal government funding is only available to federally recognized Tribes (Status of Tribes and Climate Change Working Group 2021; US GAO 2013). As of 2024 there were 574 federally recognized American Indian Tribes and Alaska Native entities in the US (Bureau of Indian Affairs 2024). This means that unrecognized Tribes, Tribes with state recognition (but not federal), Hawaiian Natives, and other Indigenous islanders lack access to these programs, inhibiting their ability to construct and adapt their water systems to climate change. Even those Tribes with federal recognition can still struggle to access and use federal and state funding. A report co-led by the Affiliated Tribes of Northwest Indians and the University of Washington Climate Impacts Group, *Climate Adaptation Barriers and Needs Experienced by Northwest Coastal Tribes*, found federal climate resilience funding to be insufficiently flexible and stated that Tribes needed greater autonomy over how to use funds (Hasert et al. 2024). They listed other barriers as well, including “stringent qualification requirements, burdensome match or personnel requirements, and funding misalignment with Tribal priorities” (Hasert et al. 2024).

In 2021, the federal government, under the Biden-Harris administration, launched Justice40 (J40) (with Executive Order 14008) to improve the equitable distribution of assistance and benefits from federal programs.[34] J40 directed more equitable allocation of existing government investments by requiring that “40% of the overall benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution” (The White House, 2021).[35] J40 required federal agencies to define “disadvantaged community” (DAC) and what “benefits” mean. In response to this executive order, federal agencies began publishing updated guidance on how states and local governments need to identify, prioritize, and engage with DACs to receive funding and other support. While the definition of disadvantaged communities alone will not ensure equitable distribution of funds, they will help to address gaps that exist in procedural justice (Swanson 2021).

34 J40 did not create any new funding programs; instead, it is a policy that directed how existing federal programs should direct the benefits of funding.

35 As of this writing, the most up to date list of programs covered by Justice 40 were published in 2023 by The White House. You can find the archived website here and here.

J40 formally called for a “whole-of-government approach to the climate crises” (Executive Order 14008, The White House 2021b). This would require new and improved levels of coordination across all government agencies and stakeholders. To support implementation and coordination of environmental justice activities across the federal government, the Biden-Harris White House launched several new offices and councils, including the Office of Domestic Climate Policy and the White House Environmental Justice Advisory Council (WHEJAC) (The White House 2021). These entities worked with the White House Council on Environmental Quality and the Office of Management and Budget to develop a federally coordinated approach to implementation of J40. They also worked on environmental justice with other federal agencies and councils, like the EPA’s National Environmental Justice Advisory Council that was established in 1993 to offer advice and recommendations about environmental justice issues and provide a forum for discussion about integrating environmental justice into EPA priorities (US EPA 2024f). The White House also established the National Climate Task Force, a group of cabinet-level federal agents, to coordinate and work across agencies on climate change mitigation as well as support implementation of J40.

> While the definition of disadvantaged communities alone will not ensure equitable distribution of funds, they will help to address gaps that exist in procedural justice.

These groups informed and influenced the implementation of J40. For example, in 2021, the WHEJAC presented a set of final recommendations on J40 and other federal initiatives related to environmental justice (US EPA 2021c). In its report, the WHEJAC detailed an extensive list of funding programs and policies to include in J40, including programs for developing clean water infrastructure and for climate mitigation and resilience. They also recommended approaches to defining “investment benefits” to help maximize federal investment benefits and avoid harm in environmental justice communities. They similarly recommended considerations for defining “disadvantaged communities” that incorporate factors such as non-attainment of clean water standards and high rates of health disparities. These recommendations were submitted to the White House Council on Environmental Quality, and one year later this council delivered a 200-page report to the US Congress detailing federal agency responses to the WHEJAC’s recommendations (The White House Council on Environmental Quality 2022). This report of agency responses demonstrated federal recognition of environmental injustice and ways to address it within federal funding and policy. However, there is no formalized mechanism for assessing the extent to which funding has met the goals of the J40 Initiative (Rosser, Shok, and Kuna 2024). As of January 20th, 2025, President Trump ended J40 along with many other equity, environmental justice, and climate resilience initiatives.

The Inflation Reduction Act (IRA) was another major source of federal funding for climate mitigation and adaptation. The IRA became law in August 2022 and primarily focused on tax credits for clean energy. However, it was paused on January 20th, 2025, by President Trump’s Executive Order Unleashing American Energy (The White House 2025b; Office of Management and Budget 2025), so its future is uncertain. Although it did not explicitly include funding specific to water, it still made significant investments in climate resilience that, in some cases, have addressed water and sanitation. For example, in February 2023, the US Department of the Interior (DOI) announced a

$728 million investment in drought mitigation and delivery of clean drinking water to Tribal and rural communities in the Upper Colorado River Basin. This included $125 million to relaunch a voluntary conservation pilot program in the Upper Colorado River Basin with the goal of protecting the water supply in Lake Powell and Lake Mead along the Colorado River (Columbia Law School and Environmental Defense Fund 2023). As of September 2024, Taylor (2024) estimated that the Biden Administration had awarded $61 billion from IRA for climate programs (excluding loans, direct government spending, and tax credits) leaving approximately $33 billion (35%) to be spent (Taylor 2024).

Another example of an IRA funding program that was used to address climate change impacts on water and sanitation was the Community Change Grants Program. The program launched under the IRA with nearly $2 billion to support communities that are the most adversely and disproportionately impacted by climate change, legacy pollution, and historical disinvestments (US EPA 2024a).[36] To be eligible for Community Change Grants, applicants were required to be part of a partnership between two community-based nonprofit organizations (CBOs) or between a CBO and a Tribe, local government, or institution of higher education. Eligible project strategies related to climate resilience and/or water and sanitation included green infrastructure and nature-based solutions to address flooding risk and reduce heat island effects, community resilience hubs that provide shelter and essential services under extreme weather, clean water infrastructure (such as septic to sewer conversions, backup wells, backup power, and lead pipe replacement), and planning efforts needed for larger water infrastructure projects (US EPA 2024g).

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36 The Community Change Grants Program funding opportunity closed in November 2024.

Furthermore, Section 50231 of the IRA provided $550 million to the Bureau of Reclamation within the DOI to provide grants, contracts, and other financial assistance agreements for DACs (as defined by BOR) to plan, design, or construct water projects in communities or households that do not have reliable domestic supplies (Columbia Law School and Environmental Defense Fund 2024). There were only 17 states and four US territories where this funding could be used (Yarmuth 2022). While there was no explicit mention of climate resilience in this section, addressing water supply reliability is critical for ensuring climate resilience for water systems in frontline communities.

States play an important role in distributing federal funding.

States play an important role in distributing federal funding. For example, states are responsible for implementing the EPA's largest funding programs for water and sanitation infrastructure, the Drinking Water and Clean Water State Revolving Loan Funds (DWSRF and CWSRF). The CWSRF was created in 1987 to provide financial assistance to help municipalities, local governments, and wastewater utilities comply with the Clean Water Act (CWA). The DWSRF was established in 1996 to provide drinking water systems with financial assistance to meet the requirements of the Safe Drinking Water Act (SDWA). Neither the CWA nor the SDWA explicitly address climate change, but they establish minimum requirements for wastewater treatment and drinking water quality that remain critical for protecting drinking water and public and ecosystem health as climate change degrades water resources (Campbell-Ferrari et al. 2024). Each state receives federal funds for its DWSRF and CWSRF and adds a required 20% state match. SRFs are operated by states primarily as low-interest loan funds for capital projects (US EPA 2023a; 2024b).[37] According to the EPA, DWSRF and CWSRF funding can be used to adapt water and sanitation systems and improve resilience (US EPA 2020a; 2023b). For example, DWSRF funds can be used for physical flood barriers, redundant equipment and infrastructure, relocation of a treatment plant, or deepening of a well (US EPA 2020a). CWSRF funds can be used for climate resilience infrastructure projects such as increasing storage capacity of sewer systems to better withstand increased precipitation and storm intensity or installing flood water pumps in wastewater treatment plants (US EPA 2023b).

Between 2000 and 2023, the DWSRF provided over $56 billion in assistance across all states and territories, including $15.8 billion to DACs for drinking water system projects (US EPA 2024h). Despite this level of funding, Hansen and co-authors (2021) analyzed DWSRF data from 2011 to 2020 (pre-BIL) and found that only 7.1% of eligible drinking water systems have received assistance through a DWSRF. They suggested that this finding indicated a need to distribute funds more broadly. Hansen and co-authors also showed that while the federal government stipulates that a maximum of 35% of SRFs can be used essentially as grants (or additional subsidization), only 26.6% of the funding had been delivered as a grant. Newer data may indicate a higher proportion of funds going to DACs because, under the BIL, additional subsidization was increased to 49% (US EPA 2022a). However, more research is needed to test this assumption. Finally, Hansen and co-authors found that water systems serving small communities received a smaller proportion of funding awards relative to the total number of eligible systems (88% of eligible systems served 3,300 or fewer people, but these

37 The forms of assistance from CWSRFs and DWSRFs include below-market rate interest, no interest, and negative interest loans; purchase of debt or refinance; guarantees or insurance for improving credit, guaranteeing SRF revenue debt, providing loan guarantees, and other forms of subsidization.

systems only received 53% of the awards) and communities with higher percentages of people of color were less likely to receive DWSRF assistance than communities with a higher percentage of White residents (on average a 10% increase in the proportion of residents who were White increased the likelihood of receiving DWSRF assistance by 0.41%).

One approach to getting more of the funding from the SRFs to frontline communities would be to prioritize these funds for equity needs. However, the Brookings Institute found that most state SRFs didn't prioritize this issue (Kane and Singer 2024). In their review of 50 state Intended Use Plans (IUPs) for CWSRF and DWSRF programs, only 33% of the CWSRF IUPs and only 34% of the DWSRF IUPs explicitly described environmental justice concerns (Kane and Singer 2024).

Smaller systems or systems serving low-income ratepayers tend to have low financial capacity, meaning that they lack sufficient operating reserves, revenue options, and financial expertise, making it challenging to access loans, which are a primary form of financial assistance from SRFs (Greer 2020; Scanlan and Husain 2022). Because of these constraints, the interest rates on the loans they are offered tend to be high and therefore infeasible to pay back (Greer 2020).

> State governments are another source of funding for climate resilience and adaptation of water and wastewater infrastructure.

Other capacity limitations cited as barriers to accessing SRF and federal funding include lack of staff expertise, institutional support, and time to apply for opportunities (Biagini et al. 2014; Glade and Ray 2022; Headwaters Economics 2024; B. Taylor et al. 2024). Analysis by Headwaters Economics of the distribution of funding from FEMA's Building Resilient Infrastructure and Communities (BRIC) program in FY 2022 found that counties with higher capacity (as measured by the Rural Capacity Index) were able to secure $1.5 billion in funding, whereas medium-capacity counties secured $251 million and low-capacity counties secured $50 million (Smith 2023a).[38] BRIC funds are specifically for pre-disaster mitigation and to help communities build resilience to climate change. BRIC funding is one of multiple funding programs that FEMA offers within its Hazard Mitigation Assistance grant programs that are available for states, Tribes, and local communities to prepare for flood, fire, extreme storms, drought, extreme heat, hurricanes, landslides or mudslides, and earthquakes (FEMA 2024c). (These programs are discussed further in Section 8.3.)

Beyond capacity limitations, federal funding programs are challenging to access even for systems with higher capacity. An analysis of federal funding programs and tools for rural and Tribal communities (broader than just for water, sanitation, and resilience, but inclusive of these components) found many federal funding programs outdated, fragmented, and confusing (Pipa and Geismar 2020). In FY 2019 there were more than 400 rural community development programs under 13 federal departments and 10 independent agencies (Pipa and Geismar 2020). Other work by Headwaters Economics found that more than 60% of climate resilience funding in the BIL requires a local match, where applicants must pay 20% to 30% of the total project cost (Smith 2023b). Match

38 Smith (2023a) did not evaluate the distribution of BRIC funds relative to county population, which would establish the per-capita distribution of this award.

requirements can place disproportionate burdens on small communities that do not have sufficient populations to achieve economies of scale (Smith 2023b). Furthermore, some state laws place additional barriers for local communities to generate revenue that is needed for a match (Tax Policy Center 2024). Smaller utilities often struggle to access low-interest loans because of their lower revenue and limited credit histories.

State governments are another source of funding for climate resilience and adaptation of water and wastewater infrastructure. For example, the Texas Water Development Board administers the Texas Infrastructure Resiliency Fund, which provides funding for flood planning, protection, mitigation, or adaptation projects (Texas Comptroller of Public Accounts 2024). It also offers a fund that helps Texas-based projects meet federal match requirements related to infrastructure climate resilience. New Mexico created the Colonias Infrastructure Fund to help pay for infrastructure projects in communities along the US-Mexico border, including for water and wastewater treatment infrastructure (New Mexico Environment Department and New Mexico Finance Authority 2022). The fund provides 90% grants, 10% loans (at 0% interest for 20 years) to entities such as local governments and others able to demonstrate capacity to construct and operate a water or wastewater project over the long term (New Mexico Environment Department and New Mexico Finance Authority 2022). However, the fund contains no specific criteria that infrastructure projects incorporate climate change considerations in planning or design of systems, potentially limiting the program's long-term effectiveness under a changing climate.

Private lenders and foundations can be sources of capital for equitable, climate-resilient water infrastructure. Building on the green bank model that uses public funding to motivate private investments in energy efficiency, clean energy, and other environmentally beneficial projects, a


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coalition of private lenders and financial institutions sent $1.3 million in awards and technical assistance to six green banks for equitable clean water infrastructure projects in 2024 (Quantified Ventures 2024). Composed of the Coalition for Green Capital, PRE Collective, and Quantified Ventures, and funded by the Robert Wood Johnson Foundation, the coalition will provide expertise to leverage the investment to support project development, provide technical assistance for implementation, and fund local staff capacity. The projects to be supported will focus on infrastructure for drinking water, stormwater management, and flooding in frontline communities impacted by climate change (Quantified Ventures 2024).

Most infrastructure funding for climate adaptation and resilience of water and sanitation systems is for centralized water and sanitation systems that serve more than one household. For example, analysis by Calabretta et al. (2022) found that around 2% of federal wastewater dollars have been invested in onsite systems. Yet nearly 20% of American households depend on onsite wastewater systems and approximately 13% use private wells for drinking water (Calabretta, Cunningham, and Vedachalam 2022). Some states and counties offer grant funding to households with domestic wells or septic systems, but in some places there are laws that prohibit the expenditure of public resources on private property or that make homeowners potentially liable for increased taxes because the funds would be considered income (Lewandowski 2024; Municipal Research and Services Center of Washington 2024; Office of the Attorney General of Texas, n.d.). This has been a challenge faced by governments working to replace lead service lines located on private property. Fortunately, in 2024 the IRS issued an announcement clarifying that federal funding for lead service line replacement funds would not be considered taxable income (Lewandowski 2024).

Most infrastructure funding for climate adaptation and resilience of water and sanitation systems is for centralized water and sanitation systems that serve more than one household ... Yet nearly 20% of American households depend on onsite wastewater systems and approximately 13% use private wells for drinking water.

Despite these challenges, funding programs do exist that can be used for onsite water and sanitation infrastructure. For example, the regional nonprofit Southeast Rural Community Assistance Partnership (SERCAP) operated a Certified Community Development Financial Institution Loan Fund that provided loans for installing a new septic system at an income-qualified household in Virginia (SERCAP News 2022). SERCAP noted that this loan was funded by United States Department of Agriculture's (USDA) Rural Development program and another SERCAP Agency Revolving Loan Fund, as well as some state-specific support, such as from the Virginia Department of Housing and Community Development. SERCAP also offered the Indoor Plumbing & Rehabilitation Flex Program, which provided low- and moderate-income homeowners with technical assistance to coordinate the installation and funding of indoor plumbing, potable water systems, and replacement of failing septic systems (SERCAP, n.d.). To date, these programs have not been designed for climate resilience nor adaptation.

States can use CWSRF funds to set aside funding for connecting homes and communities lacking safe sanitation with centralized wastewater systems. Although these funds are not specific to climate resilience, connecting households to centralized systems can provide them with greater reliability in the face of climate disruptions and improve wastewater treatment, benefiting the surrounding community. For example, the Illinois EPA created two grants — the Unsewered Communities Planning Grant and the Unsewered Communities Construction Grant Program — to help communities plan for and install connections to centralized wastewater treatment services (Landes et al. 2021). Both grant programs offer grants based on a sliding scale determined by the median household income of the applicant's service area population. For the planning grant, award amounts range from $17,500 to $30,000 (Illinois EPA 2023b). For the construction grant, the grant amount is a percentage of the total project cost, ranging from 50% to 100%, for no more than $5 million total in size (Illinois EPA 2023a). The planning grants are funded through a portion of loan repayments to the state's CWSRF, and the construction grants are funded through state bonds (Illinois EPA 2023b; Illinois EPA 2023a). These funding programs in Illinois do not require that the project consider climate change when installing new connections.

In summary, the historic levels of funding — from the BIL and IRA infused federal programs like the Tribal Community Resilience Annual Awards Program and the Community Change Grants Program, as well as the state-led CWSRF and DWSRF — helped to make progress toward this goal. The J40 Initiative should have helped expand the benefits of federal funding programs like these to frontline communities, but there remains a lack of means for measuring the initiative's impact and the initiative has been cancelled by the Trump Administration in January 2025. State programs and private lenders offer funding and financial assistance for equitable, climate-resilient water and sanitation design and construction, too. However, significant barriers remain, challenging many frontline communities with resource and capacity constraints to access and use these funds. Households with decentralized water and sanitation have some, but fewer, options for financial support for installing climate-resilient systems. Making these investments upfront and proactively will yield benefits not only for the communities but also for the entire country. Once built, however, ongoing funding will be necessary to properly operate and maintain the infrastructure, to ensure it withstands climate impacts from increasingly extreme and unpredictable weather.

> Making these investments upfront and proactively will yield benefits not only for the communities but also for the entire country. Once built, however, ongoing funding will be necessary to properly operate and maintain the infrastructure, to ensure it withstands climate impacts from increasingly extreme and unpredictable weather.

Despite billions of dollars of investments from BIL and other programs, frontline communities in the US need to be able to access and implement that funding, even as they need billions more in funding and financing to adapt and build climate-resilient water and sanitation infrastructure. Strategies and approaches that we identified for overcoming barriers and challenges to equitable funding for climate-resilient water and sanitation are:

1. Increase the amount of funding available through federal and state programs, including the CWSRF and DWSRF, that can be used to build and adapt climate-resilient water and sanitation infrastructure;
2. Ensure that funding and financing are accessible and do not have barriers for frontline communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure;
3. Enact policies that ensure frontline communities are receiving an equitable amount of benefits from climate and infrastructure funding;
4. Implement technical assistance programs to address barriers experienced by frontline communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure; and
5. Offer programs to help construct climate-resilient, decentralized water and sanitation infrastructure and/or to connect homes and communities with decentralized infrastructure to more climate-robust centralized systems.

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8.2 FUNDING AND ASSISTANCE FOR CLIMATE-RESILIENT OPERATIONS AND MAINTENANCE

Attribute description: Climate-resilient O&M for water and sanitation systems in frontline communities have adequate and sustainable funding and assistance.

Operations and maintenance (O&M) activities of equitable, climate-resilient water and sanitation projects for frontline communities are rarely eligible for government and private funding and financing (EBP and American Society of Civil Engineers 2021; US GAO 2016). For example, the BIL did not include any funding for O&M (The White House 2022a), which is a chronic challenge across many government programs. Yet, even basic O&M of water and wastewater infrastructure can be expensive and requires a certain level of technical expertise by staff (Landes et al. 2020). This is especially true in small, rural, and Tribal communities that lack the capacity and sufficient funding to prepare for or respond to climate change (B. Taylor et al. 2024).

Water and wastewater systems serving small communities are at a particular disadvantage when trying to fund O&M. In communities with small customer bases or high proportions of low-income households, drinking water and wastewater systems often struggle to collect enough revenue to effectively operate and maintain their systems (Feinstein et al. 2020, Greer 2020). In these communities, raising water rates may not be feasible. Furthermore, small systems may have difficulties hiring experienced people to operate and manage systems due to financial constraints and/or limited workforce in the area (Glade and Ray 2022).

Without investments in water system maintenance, infrastructure deteriorates, which threatens public health, reduces water quality, and makes systems more vulnerable to climate change impacts (Hansen et al. 2021). Yet government grants and other forms of direct financial assistance for O&M are uncommon. The federal government allows states to use a portion of DWRSF funds, called "set-asides," for capacity development, operator certification, and technical assistance for water systems — but these funds cannot directly cover ongoing O&M activities (US EPA 2024c).

> Water and wastewater systems serving small communities are at a particular disadvantage when trying to fund O&M.

At least one state has made funding available for equitable, climate-resilient O&M. California's Safe and Affordable Drinking Water Fund provides financial assistance for O&M as one of its priority activities (California State Water Resources Control Board 2024a). This fund is separate from the state's DWSRF and is administered through the Safe and Affordable Funds for Equity and Resilience (SAFER) Program, which was designed to provide support and resources for Californians who lack safe, adequate, and affordable drinking water (California State Water Resources Control Board 2024b). The program and funding are explicitly designed to address climate resilience and equity by supporting O&M tasks at water systems that fail to provide safe, affordable drinking water so that they can comply with federal and state drinking water laws.

Free technical assistance that includes the performance of O&M may provide financial relief for water and wastewater systems in frontline communities. For example, the US Department of Agriculture's Circuit Rider Program, the Rural Community Assistance Partnership (RCAP), and the EPA's Environmental Finance Centers (EFCs) are three technical assistance providers that serve small, rural, and/or underresourced water and wastewater systems (Rural Community Assistance Partnership, n.d.-a; US Department of Agriculture, n.d.-a; US EPA, OW 2024b). One of the ways these assistance providers support water and wastewater systems is by helping them find and apply for funding to build climate resilience. The free technical assistance from these programs, however, is not focused on climate resilience. This is in part because the technical assistance providers lack sufficient funding themselves to address climate resilience in their support efforts (B. Taylor et al. 2024).

Households with onsite water and sanitation systems are responsible for the O&M costs for their systems. Climate change impacts — such as rising groundwater tables due to sea level rise or flooding from extreme storm events — are causing onsite systems to fail (Pacific Institute and DigDeep 2024). Homeowners in frontline communities need low or no-cost training or assistance with managing and operating their onsite systems as the climate changes. RCAP works for free directly with rural homeowners with private wells and onsite wastewater systems to train and assist them in ensuring their systems are functioning properly. For private well owners, RCAP can provide individual well assessments and water quality sampling; for households with onsite wastewater systems, they offer training on maintenance and upkeep (Rural Community Assistance Partnership, n.d.-b). RCAP education and outreach includes workshops, webinars, self-paced e-learning, podcasts, brochures, and a hotline. These efforts are typically supported by local cooperative programs with state health departments, county or local health districts, well driller associations, state extension offices, realtors, environmental laboratories, and local philanthropic organizations (Rural Community Assistance Partnership, n.d.-b). However, climate resilience and adaptation are not explicitly addressed in RCAP's private well and onsite wastewater program materials.

Homeowners in frontline communities need low or no-cost training or assistance with managing and operating their onsite systems as the climate changes.

The USDA Rural Development Program offers a Single Family Housing Repair Loans and Grants program (under Section 504) for low-income households in all 50 states (US Department of Agriculture, Rural Development 2015). The loans and grants are for an array of household needs, and can be used for replacement, maintenance, and installation of onsite water and wastewater systems. Grants through the program have both income and age requirements (50% of median household income; over 61 years of age), making it challenging for some to access these funds (Calabretta, Cunningham, and Vedachalam 2022). The USDA does not specify that activities covered by loans or grants from the program address climate resilience of O&M of onsite systems, but regular maintenance activities help contribute to the reliability of onsite systems during extreme climate events.

If well-funded and designed to address climate resilience, O&M can help prevent disruptions or damage to water and sanitation systems. Still, when disasters do occur, frontline communities may need additional financial assistance and resources to respond and restore water and sanitation access. Some strategies and approaches for funding and assisting frontline communities with climate-resilient O&M are:

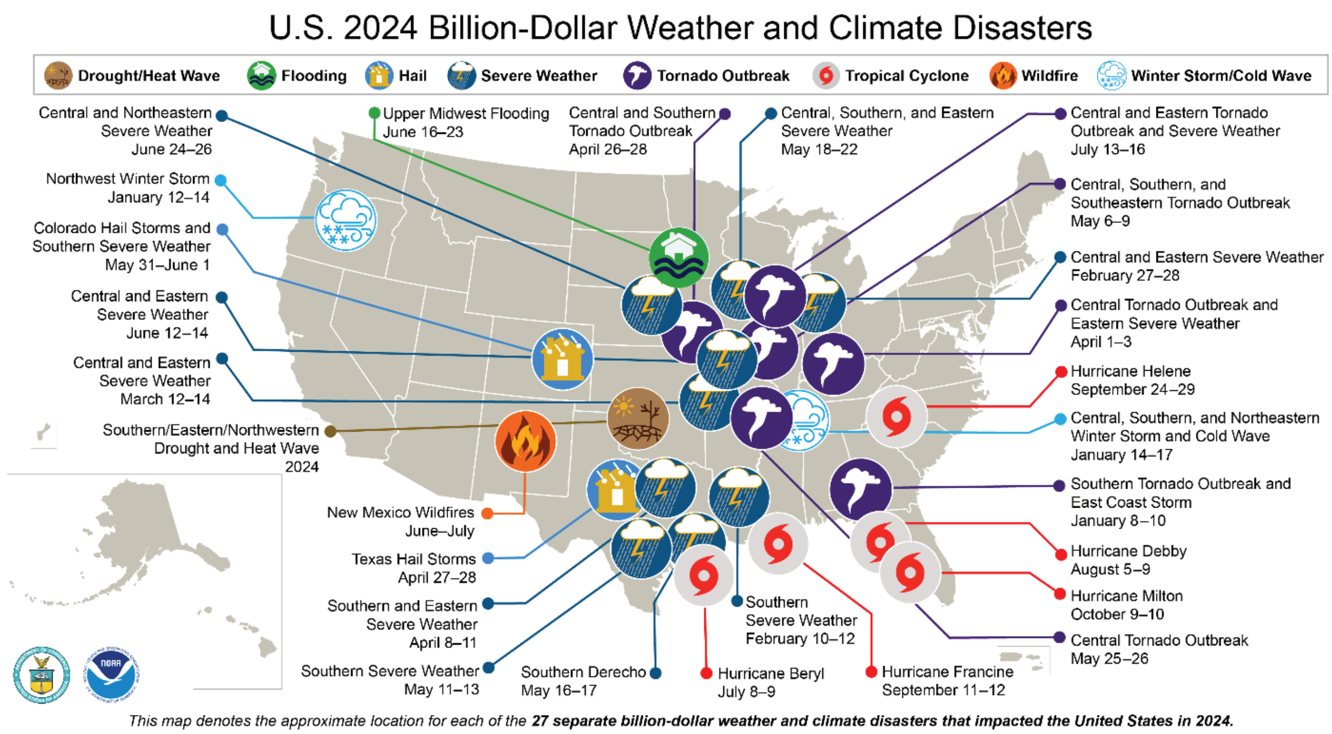
1. **Create and fund federal and state grant programs that explicitly name climate resilience and O&M as funding priorities for water and sanitation systems;**
2. **Offer O&M as an activity available through technical assistance providers; and**
3. **Fund and train technical assistance providers on climate-resilient O&M.**
4. **These strategies and approaches can help reduce the long-term cost burden for frontline communities, helping ensure that they have reliable and climate-resilient water and sanitation infrastructure into the future.**

8.3 FUNDING AND FINANCING FOR CLIMATE DISASTER PREPAREDNESS, RESPONSE, AND RESTORATION OF WATER AND SANITATION

Attribute description: Frontline communities have access to adequate funding, financing, and disaster insurance for disaster preparation, mitigation, response, and restoration so that water and sanitation can be equitably restored after a climate disaster.

On average, the US now experiences a billion-dollar weather or climate disaster every three weeks, whereas in the 1980s, billion-dollar weather or climate disasters happened approximately once every four months (Jay et al. 2023). These disasters include extreme storms such as hurricanes, tornados, and severe winter storms as well as inland flooding, droughts, heatwaves, and wildfires. As of this writing, 2023 had 28 billion-dollar weather and climate disasters — the highest recorded number to date — with a total cost of at least $92.9 billion (A. Smith 2024). In 2024, there were 27 confirmed billion-dollar weather and climate disasters (Figure 10) (NOAA National Centers for Environmental Information 2025).

FIGURE 10. 2024 Billion-Dollar Weather or Climate Disasters in the United States



Source: NOAA National Centers for Environmental Information 2025

During and following a climate disaster, water and sanitation systems may need extra or specialized equipment, expertise, and labor to restore service, perform immediate and long-term repair, or replace infrastructure and other components. Households that lose access to running water and functioning plumbing may also need emergency water supplies or sanitation services to survive until their systems are repaired (Pacific Institute and DigDeep 2024). In worst-case scenarios, whole communities can become displaced from their homes, as occurred in 2017 after Hurricane Harvey in the Houston area of Texas killed nearly 100 people and displaced approximately 32,000 others (The New York Times 2017).

Because water and sanitation access are fundamental to life and the economy, loss of access for communities can lead to major losses in life, property, infrastructure, and economic output. After Hurricane Harvey, 61 drinking water and 40 wastewater facilities were inoperable, and 203 boil water notices were issued by drinking water facilities in Texas (US EPA 2019a). All but one of the wastewater facilities had operations restored during the three-week emergency response period; the one wastewater facility that was not restored was destroyed and not rebuilt (US EPA 2019a). An estimated 130,000 to 260,000 private domestic wells were inundated by floodwaters resulting in 1.7 to 2.5 times the risk of Escherichia coli (E. coli) contamination for these private well users (Pieper et al. 2021). Hurricane Harvey caused approximately $125 billion in damage and remains one of the costliest disasters since record keeping began in the early 1980s (Blake and Zelinsky 2018; NOAA National Centers for Environmental Information 2025). The actual costs are almost certainly higher because this estimate did not include residential flood loss claims from outside the designated flood plain, where there was low participation in the National Flood Insurance Program (NFIP) (Blake and

Zelinsky 2018). The NFIP's program design still needs a comprehensive update to account for the changing flood risks and needs a more inclusive community eligibility requirement to reduce gaps in equitable, climate-resilient coverage (Campbell-Ferrari et al. 2024). Black, Hispanic, disabled, and low-income communities in areas not covered by federal flood insurance suffered the worst in myriad ways, from disabilities preventing preparation or response to financial constraints, among other challenges (Flores et al. 2021; Billings, Gallagher, and Ricketts 2022; Payton et al. 2023; Chakraborty, Grineski, and Collins 2019).

Shifting climate patterns drive extreme cold and freezing events that threaten water and sanitation access and can dramatically increase response and recovery costs (Pacific Institute and DigDeep 2024). For example, Winter Storm Uri in 2021 left Texas with $80 billion to $130 billion in damages from lost economic activity, contaminated water supplies, and loss of lives (Golding, Kumar, and Mertens 2021). Loss of power, burst pipes, and frozen equipment at water treatment and distribution centers left an estimated 49% of Texans without running water for an average of 52 hours (Glazer et al. 2021). Another 14 million people received boil water notices due to potential contamination from drops in pressure (Glazer et al. 2021). People served by very small water systems (25 to 500 people) did not have adequate water for an average of eight days following the storm, while people served by larger systems had adequate water restored in an average of 4.7 to 5.5 days (Glazer et al. 2021). Boil water notices lasted more than 30 days in some locations (Glazer et al. 2021). One post-disaster analysis found that costs incurred from impacts of Winter Storm Uri by those who experienced disruptions due to burst water pipes, lack of hot water, and challenges related to COVID-19 averaged $61 per household above the average cost incurred from disruptions to information, lighting, and food access (Peterson et al. 2024).

> The National Flood Insurance Program's design still needs a comprehensive update to account for the changing flood risks and needs a more inclusive community eligibility requirement to reduce gaps in equitable, climate-resilient coverage.

Water and wastewater systems serving frontline communities need access to funding for climate disaster preparedness and mitigation. Climate disaster preparedness and hazard mitigation help water and wastewater systems to better withstand a climate disaster, minimize damage from the event, and enable them to resolve disruptions to service more quickly (US EPA 2024c). Community preparedness actions can include developing emergency, disaster, or hazard mitigation plans, gathering supplies, buying insurance, preparing defenses such as strengthening water intakes to prevent damage from flooding or reducing fuel loads around facilities vulnerable to wildfires, and seeking information (such as contact information for state Water and Wastewater Agency Response Network) (Thomas et al. 2018; US EPA, OW 2023; 2024c). Yet many small, rural, and/or underresourced communities lack the capacity and financial resources to carry out many of these activities (Rural Health Information Hub, n.d.; B. Taylor et al. 2024; Thomas et al. 2018).

Federal funding for climate-related hazard mitigation for water and wastewater utilities is offered through several funding programs through FEMA. Three examples are FEMA's Building Resilient Infrastructure and Communities (BRIC) program, Hazard Mitigation Grant Program (HMGP), and Flood Mitigation Assistance (FMA) program. Each has slightly different purposes, eligibility conditions (such as an existing Presidential Disaster Declaration or insurance through the National Flood Insurance Program), and funding terms and conditions (US EPA, OW 2024c). Activities supported by BRIC include identifying hazard mitigation actions and implementing projects that reduce risk to climate hazards, building partnerships to increase investment impacts, supporting adaptation, and enforcing codes and standards to reduce community-wide risks, or reducing disaster losses and protecting life and property. The HMGP program is only available after a Presidential Disaster Declaration to help communities reduce the risk of future disasters. The FMA program provides assistance for NFIP-insured structures to elevate, relocate, or be acquired, and can also support flood reduction and prevention activities. For other FEMA programs that help build climate-related hazard mitigation or support recovery from climate-related disasters, see FEMA's Hazard Mitigation Assistance Grants website.

Examples from the past several decades demonstrate some ways these funding programs have contributed to preparing water and sanitation systems in the US for climate disasters. In Lincoln, Nebraska, flooding threatened the operability of the wastewater treatment plant, especially during and after severe storms. In 1998, the wastewater system secured a FEMA HMGP grant for $172,500, contributing to the construction of a six-foot wall to protect the substation and raising the existing electrical transformer by 3 feet above the 100-year flood plain (FEMA 2020a). In Minot, North Dakota, a major flood in 2011 forced the city to issue boil water notices and raised alarm around the potential health impacts of flooding on the drinking water system. The city secured a $2.1 million grant from the HMGP to help construct a 14-foot wall around the water treatment plant (FEMA 2020a). In Houma, Louisiana, a DAC, the drinking water system lacked adequate backup power to ensure that water supplies could be delivered if power were to be knocked out by severe weather, such as a hurricane. The drinking water system received $372,490 from the HMGP to install a 300-kilowatt backup diesel generator and automatic transfer switch at the water pump station (FEMA 2024a).

> Surveys of state officers in charge of FEMA's Hazard Mitigation Assistance programs in 43 states found many shortcomings in their ability to equitably manage these programs, including limited understanding of underserved communities, poor procedures for identifying and engaging with underserved communities, and limited local engagement in local conferences, trainings, meetings, and policy discussions.

While some communities have been successful in obtaining federal climate hazard mitigation grants, this can be challenging for small, low-resourced water and wastewater utilities to access the funding from these programs (Alaska Native Tribal Health Consortium 2024; Rural Health Information Hub, n.d.). For example, surveys of state officers in charge of FEMA's Hazard Mitigation Assistance programs in 43 states found many shortcomings in their ability to equitably manage these programs, including limited understanding of underserved communities, poor procedures for identifying and engaging with underserved communities, and limited local engagement in local conferences, trainings, meetings, and policy discussions (Vilá et al. 2022).

The Alaska Native Tribal Health Consortium documented many barriers that Alaska Native communities face when trying to access federal funding for hazard mitigation. It found only three federal programs that support protect-in-place, managed retreat, and relocation of their communities, through the Denali Commission (a congressionally established federal agency in Alaska), Bureau of Indian Affairs, and USDA, rather than through FEMA (Alaska Native Tribal Health Consortium 2024).[39] Grants from FEMA's BRIC tend to go to higher capacity, large cities, in part because match requirements can prevent rural and low-capacity communities from applying for these funds (Smith 2023a).

Funding is also needed for response and recovery from the impacts of climate change. Financial assistance for response and recovery from climate disasters can come in many forms. The federal government offers help with temporary housing, delivery of bottled water and other emergency supplies, hazard insurance programs, reconstruction of damaged infrastructure, and low-interest loans to assist private property owners in restoring their affected property (Howell and Elliott 2019). FEMA's disaster assistance for individuals and families focuses on covering costs related to temporary housing, repair or replacement of owner-occupied homes, damage to vehicles, food and water supplies, disaster-related medical expenses, and other immediate assistance needs (FEMA 2024b). Individuals with insurance need to submit an insurance claim and provide FEMA with a denial letter for certain expenses (FEMA 2024b). Tribal communities, rural communities, renters, and non-US-born households are more likely to lack flood insurance than predominantly White, urban, homeowners and US-born households, leaving these groups at a higher risk of exposure to economic losses from flooding (A. Maldonado, Collins, and Grineski 2016; US GAO 2013). Additionally, water systems and households in communities that do not participate in or qualify for the NFIP because FEMA has not mapped their area for flood hazards are not eligible for federal flood insurance (Campbell-Ferrari et al. 2024; US GAO 2013). There are still rural and Tribal lands that have not been mapped by FEMA for flood hazards. In two-thirds of states, areas with a higher proportion of people of color had a higher share of unmapped flood risk compared with the statewide average (Flavelle et al. 2020).

The Emergency Community Water Assistance Grant program from the US Department of Agriculture offers loans or grants to rural water systems recovering from climate-related emergencies that have affected drinking water access (US Department of Agriculture 2023). This program is administered through local rural development offices. To be eligible, the community must have a median household income (MHI) less than the state's MHI for nonmetropolitan areas. These

39 The three programs that they have found to be effective in supporting Alaska's environmentally threatened communities were the Denali Commission Village Infrastructure Protection Program, the Bureau of Indian Affairs Tribal Community Resilience Program, and the Natural Resources Conservation Service Emergency Watershed Program (Alaska Native Tribal Health Consortium 2024). The Village Infrastructure Protection Program has received no new recurring appropriations (Denali Commission, n.d.). The Tribal Community Resilience Program received funds from the BIL and IRA, however Fiscal Year 2024 marked the final year of increased available funding made possible through these laws (Bureau of Indian Affairs, Office of Trust Services 2024). The Emergency Watershed Program also received funding through the BIL and IRA, both of which were "paused" in January 2025 by the Trump Administration (Office of Management and Budget 2025).

loans and grants to repair breaks or leaks in distribution lines and address related maintenance necessary to replenish water supply can be accessed by rural areas with populations under 10,000, governments, Indigenous groups, colonias, or nonprofits. Notably, the types of events that qualify as an emergency include droughts, floods, tornados, hurricanes, as well as some non-climate disasters like earthquakes. Applicants do not need a federal disaster declaration to be eligible but require documentation that damage or destruction of the system was outside the owner's control and not due to deferred maintenance (Reynolds 2024). Grants up to $1 million are available for repair of source water intake systems or up to $150,000 for distribution system repairs (Reynolds 2024).

For federally declared disasters, FEMA also has a Public Assistance Program to support recovery efforts that provides supplemental grants to states, Tribes, territories, local governments, nonprofit organizations, or facilities, including water and wastewater utilities and flood control structures like dams (FEMA 2020b). These grants can be used for debris removal, repair or replacement of damaged equipment and supplies, and restoration of facilities damaged by a disaster (FEMA 2020b). The assistance from the Public Assistance Program extends to adding hazard mitigation measures so that buildings and communities are better protected from future disasters (FEMA 2020b). The funds will not cover preexisting damage from lack of regular maintenance (FEMA 2020b), which may pose a challenge for water and sanitation systems that lack capacity and funding for adequate maintenance.

For federally declared disasters, FEMA has a Public Assistance Program to support recovery efforts that provides supplemental grants to states, Tribes, territories, local governments, nonprofit organizations, or facilities, including water and wastewater utilities and flood control structures like dams.

For non-federally declared disasters, or to supplement support from the federal government, informal groups and NGOs often provide resources and financial assistance to help individuals respond to and recover from climate disasters (Mathias et al. 2022). For example, local chapters of the American Red Cross respond to an average of 65,000 disasters every year, including wildfire, hurricane, and flooding disasters (American Red Cross 2024). They provide meals, temporary shelter or hotel stays, and support to help individuals and families access aid. One problem with depending on NGOs for disaster recovery and response is that the services provided can vary from community to community, and they may not always be well organized and coordinated with government response agencies (Sledge and Thomas 2019). For example, in Sonoma County, California where wildfires burned down more than 5,600 structures and killed 22 people in 2017, a nonprofit representative said that their organization struggled to coordinate with local government and the Red Cross and was unable to direct people to where to donate items or find information (Sledge and Thomas 2019). In nearby Napa County, also severely impacted by the fire, coordination between NGOs and local government was reportedly successful because of a preexisting Community Organizations Active in Disaster group (Sledge and Thomas 2019).

While droughts are not recognized as disasters in the same way as more acute events like floods or hurricanes, running out of water supplies or a broken water treatment system can be disastrous. California's Safe and Affordable Funding for Equity and Resilience program (SAFER), through the State Water Resource Control Board (SWRCB), is a state-funded program that offers drought emergency and interim financial support (California State Water Resources Control Board 2024c). SAFER funding can be used to help water systems or households with domestic wells purchase or obtain interim water supplies and to repair broken water treatment equipment for systems that fail to meet federal and state drinking water quality standards. The SAFER program prioritizes small, disadvantaged communities (defined by the SWRCB as a community of no more than 10,000 people in which the MHI is less than 80% of the statewide annual MHI). In the 2024–25 Fund Expenditure Plan, SAFER priorities also included ensuring consistency with the goals set by the SWRCB's Racial Equity Resolution and associated Racial Equity Action Plan, which both explicitly recognize historical and present-day racial injustices in water access and set forth measurable goals to achieving more racial equity in water access in California (California State Water Resources Control Board 2024c).

> While droughts are not recognized as disasters in the same way as more acute events like floods or hurricanes, running out of water supplies or a broken water treatment system can be disastrous.

Climate disasters are expected to increase (Marvel et al. 2023) and as they do, they will contribute to growing wealth inequality (Howell and Elliott 2019). Howell and Elliot's analysis of the relationship between local hazard damages and wealth inequality found that as hazard damages increased, "wealth inequality increase[d], especially along lines of race, education, and homeownership." Notably, the most extreme wealth inequality was found in counties that received the most federal disaster aid, suggesting that this aid may have contributed to wealth inequality along racial, and educational lines as well as for those with less initial wealth (Howell and Elliott 2019). For example, the authors demonstrated that Black households in counties that received hundreds of millions of dollars in FEMA aid had less wealth over time than their counterparts in counties that received very little FEMA aid. For white households, however, the trend was the opposite.[40]

These disparities are driven by several barriers and challenges that disproportionately impact disaster recovery for low-income communities and communities of color. After disaster damages, low-income households and non-property owners tend to end up with financial liabilities from job loss, having to move, or paying higher rents due to reduced housing stock; and at the same time, these groups have to use personal savings (if they exist) to compensate for expenses (Howell and Elliott 2019). Furthermore, during disaster response efforts, the federal government at times has suspended legal protections for low-wage workers to speed recovery, with disproportionate negative impacts on wages and job security for low-income residents (Fussell 2011). Another major problem is the inequitable distribution of disaster recovery funding based on property ownership rather than

40 The authors investigated FEMA aid at the county level and household wealth by race within each county from 1999-2013. The amount of FEMA aid received by each county during the study period ranged dramatically from under $1,000 to over $7.5 billion.

community needs (Howell and Elliott 2019; Drakes et al. 2021). Complex application processes for receiving post-disaster aid disadvantage certain groups such as foreign-born and less educated households (Grube, Fike, and Storr 2018).

After extreme storms, water and wastewater utilities may be challenged with a loss of customers and ratepayers as people are displaced for prolonged periods. As service demand falls, so may revenues, hindering a utility's ability to repair and maintain damaged systems or make bond payments on outstanding debt, which can lead to defaulting on loan payments (Congressional Research Service 2006). Customers who remain and continue to be served by financially struggling water and wastewater utilities can be at greater risk of receiving lower-quality services (Feinstein et al. 2020).

Grassroots organizations like Gulf South Rising have showcased how locally driven financing programs can increase climate resilience for frontline communities, which tend not to benefit from traditional resources post-disaster (Gulf South Rising 2019). Gulf South Rising was a coordinated regional movement in Texas, Mississippi, Alabama, and Florida for mobilizing community power to generate solutions to climate disasters in a region burdened by racialized oppression (Gonzalez 2017). They developed the Community Controlled Fund, which was grounded in shared values and directed by frontline communities' vision for shared liberation (Gulf South Rising 2019). The community fund allocated resources to support priorities identified by the community, focusing on collective healing and a just transition — both essential to preparing for and recovering from the impacts of climate change (Gulf South Rising 2019). (For more information on the process of developing a grassroots community financing program for disaster recovery, see *Gulf South Rising's Community Controlled Fund: A Recipe for Grassroots Community Financing*).

Homeowners or renters whose homes are damaged by water infrastructure failure have fewer support options for recovery from climate disasters. For example, sewer backups caused by intense rain events or flooding from severe storms are not covered by most homeowners' insurance policies. They are costly to clean up, pose an immediate health risk due to exposure to microorganisms, viruses, and parasites in raw sewage, and can lead to longer-term health risks from mold growth if cleanup isn't performed adequately (US EPA 2006). In places like New York City and Baltimore, sewer backups are more common in low-income, predominantly Black neighborhoods, and are only becoming worse as the climate changes (Mazurek 2022; Donovan 2022; R. Scott 2022). In Baltimore, the community-based organization Blue Water Baltimore and its partners initiated a community-led research project to evaluate the cost of the backups and to provide those impacted with information and support (Mazurek 2022). This research helped inform the City of Baltimore about community needs to improve the city's sewer backup support programs, including the Expedited Reimbursement Program and Sewage Onsite Support Cleanup Program. New York City's Department of Environmental Protection offers property owners' water and sewer line insurance through a private insurance company (New York City Department of Environmental Protection 2024).

Households with onsite water and sanitation systems will also need support to recover their systems from the increasing impacts of climate change. While it is not common, some states do offer them recovery assistance. After devastating wildfires in 2020, the Oregon Health Authority offered domestic well testing to ensure that water in private wells was safe to drink, though it did not offer funding to help homeowners repair damaged wells (Oregon Health Authority, n.d.). The USDA's Section 504 Home Repair Program provides loans and grants for "very-low-income homeowners" to repair certain household items like wells and septic systems (US Department of Agriculture, Rural Development 2015). The need for these types of programs that support repair and recovery of onsite systems will only grow as climate change advances.

When a climate disaster causes loss of access to water and sanitation, frontline communities need immediate and long-term financial assistance to respond and recover access. These expenses can add up quickly, and evidence suggests that disaster preparedness and mitigation will provide more cost-effective and life-saving benefits for communities. Strategies and approaches to climate disaster mitigation, response, and recovery of water and sanitation for frontline communities are:

1. **Increase funding available through federal community preparedness and climate hazard mitigation programs and expand access to these programs for frontline communities;**
2. **Expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities;**
3. **Ensure that climate disaster response and recovery efforts do not exacerbate or increase wealth inequality;**
4. **Fill gaps in government aid with local efforts by grassroots coalitions and NGOs to create local financing options and climate disaster recovery; and**
5. **Provide households at risk of sewer backups or damage to their onsite water or sanitation systems with insurance and funding assistance to recover from climate disasters.**

These strategies and approaches not only help frontline communities protect their access to water and sanitation from climate disasters, but they help prevent financial hardships that are exacerbated by these events. The following section discusses funding and financing to help frontline communities that seek to pursue alternative approaches to disaster mitigation and climate resilience of water and sanitation.

8.4 FUNDING AND FINANCING FOR ALTERNATIVE APPROACHES TO EQUITABLE, CLIMATE-RESILIENT WATER AND SANITATION

Attribute description: Nature-based solutions (NBS), green infrastructure (GI), water efficiency, and reuse have sustainable, adequate funding sources to be implemented at scale in support of climate-resilient water and sanitation for frontline communities.

Alternative approaches such as NBS, GI, water efficiency, and reuse are increasingly recognized for their important contributions to climate adaptation and resilience for communities and their water and sanitation systems (Vigerstol et al. 2023; US Global Change Research Program 2023; International Water Association, n.d.). Funding and financing for these approaches vary by the scale of the project, the location, whether it's on public or private property and whether the benefits derived from the project are created for the public or for private entities (including households). Here, NBS projects refer to "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges, effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016). NBS includes GI projects, and here GI refers to interconnected, built urban ecosystems and infrastructure that function together to provide a variety of benefits for water quality, quantity, biodiversity, air quality, urban heat, recreation, and beautification (Grabowski et al. 2022). Funding and financing for GI is often separate from NBS because GI is typically implemented by urban agencies or private property owners to address regulatory requirements related to stormwater management. Drivers of NBS projects tend to be related to ecological restoration, water quality and quantity improvement, biodiversity, and climate resilience. The stakeholders involved in funding and implementing these projects can range from federal and state agencies and Tribal entities to environmental nonprofits and large landowners like farmers. NBS can be implemented in nonurban environments on agricultural or undeveloped land and at scales that are intended to provide benefits beyond a single property or site.

Water efficiency refers to efforts that focus on adopting technology — like high-efficiency toilets or drip-irrigation systems — that help maximize the effectiveness of water use and minimize waste. Water efficiency practices tend to be implemented by individual property owners but may be subsidized or paid for with public dollars, such as from water utilities that are seeking to reduce water demand and prepare for a future with greater water supply variability. Water reuse is the practice of reusing wastewater treated only to the degree necessary for the intended end use. Households can reuse water with a greywater system that captures wastewater from a sink and applies it for use in a toilet, while community-scale reuse systems operated and maintained by wastewater utilities or municipalities treat wastewater and then reuse it for irrigation, industrial processes, or drinking. Funding for water reuse depends on the scale and property type and end use.

Funding and financing options are needed to implement these solutions at scale in support of climate-resilient water and sanitation for frontline communities. Funding for these types of approaches can be difficult to obtain because government and private funding programs for climate adaptation of water and sanitation tend to support more traditional infrastructure, focus on new water supply development, or address post-disaster recovery rather than proactive adaptation (Dhakal and Chevalier 2017; Wasley et al. 2023; Vigerstol et al. 2023). Global estimates by the United Nations Environment Program indicated that NBS funding (not including for GI) was $154 billion in 2022 and needs to increase to $484 billion by 2030 to meet global Sustainable Development Goals for climate, biodiversity, and land protection (United Nations Environment Programme 2022). Funding and financing also need to be available for adoption of these strategies at multiple scales such as by households, a single community, or for multiple communities within a watershed.

Funding and financing for alternative approaches in frontline communities are critical to ensure they have access to these solutions. These approaches can be cost-effective ways of adapting to climate change, mitigating greenhouse gas emissions, and providing other water, sanitation, and affordability benefits (Cross et al. 2021; Cooley, Shimabuku, and DeMyers 2022; Cooley et al. 2020; Cooley, Phurisamban, and Gleick 2019; Vigerstol et al. 2023; International Water Association, n.d.). NBS approaches can reduce flood risk and drought hazards (Vigerstol et al. 2023), thereby addressing two major impacts of climate change on water and sanitation (Pacific Institute and DigDeep 2024). Without funding and financing for these approaches, frontline communities will fall short of their goals to holistically adapt and build climate-resilient water and sanitation (Bertana et al. 2022).

> Funding and financing also need to be available for adoption of these strategies at multiple scales such as by households, a single community, or for multiple communities within a watershed.

There are several challenges related to funding and financing NBS, GI, water efficiency, and reuse. Costs and benefits of these strategies are less well known, and, in some cases, harder to quantify relative to grey infrastructure approaches (Roy et al. 2008; Brill et al. 2023). For NBS and GI, project costs are highly specific to the intervention, the scale of the intervention, and local context, and therefore are not readily transferrable between project sites (Václavík et al. 2016; Raymond et al. 2017). Funding agencies can require progress reports with tangible and quantifiable solutions, but these generalized measures of “success” may not address the fundamental social, economic, and political aspects of climate adaptation of more transformative approaches — especially of concern on issues of justice and equity (Bertana et al. 2022). To fund and finance NBS for water and climate resilience, financial institutions may need to develop new project management cycles, implementation protocols, and monitoring frameworks (Vigerstol et al. 2023; Bennett and Ruef 2016).

Multiple federal agencies offer funding for NBS. According to the National Wildlife Federation’s Nature-based Solutions Funding Database, ten federal agencies offer dozens of programs that fund, finance, or provide technical assistance and capacity building for NBS projects (National Wildlife

Federation 2022). Of these, about a third do not have cost-share[41] requirements, which may make them more accessible for frontline communities with resource constraints. One such program was the Climate Resilience Regional Challenge, a one-time program from NOAA that supported NBS projects for coastal communities facing climate impacts from storm surge, hurricanes, drought, and sea level rise (NOAA 2024c).[42] A fundamental aspect of the program was that grant recipients were required to ensure frontline communities benefitted from the funded projects (NOAA 2024c). The Maine Governor's Office of Policy Innovation and the Future received $69 million from this source to implement its climate action plan, including NBS activities that support underserved, rural, and Tribal communities to develop and implement climate adaptation strategies for reducing flood risk, saltwater intrusion, and for protection of built infrastructure (NOAA 2024b).

State agencies also fund NBS projects for climate resilience. North Carolina has a robust Resilient Coastal Communities Program designed to help the state prepare for climate change impacts. This program comes directly from the North Carolina Climate Risk Assessment and Resilience Plan that facilitates collaboration across state agencies to address some of the state's greatest vulnerabilities to climate change. The plan proposes strategies that include NBS, GI, and stormwater management and highlights the need to reduce risk and increase resilience as climate-related impacts become more severe, most especially for frontline communities (State of North Carolina, Governor's Office 2020).

In New Bern, North Carolina, the Duffyfield Community Resilience Improvement-Rose Street Basin Restoration and Enhancement project received a $175,320 grant through the Resilient Coastal Communities Program, in addition to other state and federal funds (North Carolina Environmental Quality 2023). The project was selected because it reduces vulnerability of a critical population using a nature-based or hybrid solution. Once complete, the project will include swales and forested wetlands to help capture rainwater, treat and store stormwater, and buffer high-tide events, helping to mitigate flood impacts in a community space while protecting downstream residents from the risk of flooding (North Carolina Environmental Quality 2023).

Green infrastructure projects are often pursued by municipal governments in urban communities for stormwater management and to meet regulatory sewer overflow requirements.

Green infrastructure projects are often pursued by municipal governments in urban communities for stormwater management and to meet regulatory sewer overflow requirements. However, there is a lack of financial incentives for private property owners to install and manage GI (Dhakal and Chevalier 2017). In the US, some municipalities have created stormwater utilities to help fund GI on public and private property. The Charlotte-Mecklenburg Storm Water Services launched in the early 1990s as one of the country's first stormwater utilities and the first in North Carolina (City of Charlotte 2024a). The joint municipal and county stormwater utility proactively manages the stormwater drainage system in response to climate change impacts

41 Cost-share refers to the amount of money or the proportion of funding for a project that must come from a source other than the funding agency.

42 NOAA does not plan to offer a second Climate Resilience Regional Challenge (NOAA 2025).

by providing services that help protect the quality of streams and other surface waters, mitigate flooding, and improve drainage infrastructure (Charlotte-Mecklenburg Storm Water Services 2021). The utility's stormwater system includes ditches, curbs, storm drains, retention basins, and GI to protect the public and the environment (Charlotte-Mecklenburg Storm Water Services 2021). The utility charges service fees based on a property's impervious surface area that are included in residents' bills as a separate monthly fee ranging from $9.19 for Tier 1 (<2,000 square feet of impervious surface) to $31.14 for Tier 4 (5,000 square feet or more of impervious surface) (City of Charlotte 2024b). While nominal for some, the city government understands that not all residents can afford these fees and therefore offers an assistance program for those experiencing financial challenges (Charlotte Water 2024). However, research suggests that utility customer assistance programs, where they exist, fail to offer meaningful levels of assistance for the lowest income brackets, especially in large metropolitan areas (Vedachalam and Dobkin 2021).

Federal funding is also available for GI in support of climate resilience goals. Within state CWSRFs and DWSRFs, the Green Project Reserve (GPR) was established by Congress in 2009 "to guide funding toward projects that utilize green or soft-path practices to complement and augment hard or gray infrastructure … help utilities adapt for climate change … and promote innovative approaches to water management problems" (US EPA 2012).[43] Funding for the GPR is left up to the discretion of states, but Congress required that no less than 10% of SRF capitalization grants should be part of the GPR (US EPA 2012). For a GI project to receive funding from the GPR it must improve source water quality and/or quantity and maximize the reliance on natural hydrologic functions (US EPA, OW 2017a). Examples of eligible GI projects include pervious or porous pavement, bioretention, green roofs, rainwater harvesting cisterns, and xeriscape and drought-resistant landscaping (US EPA, OW 2017a). J40 required that 40% of the benefits of GPR projects go toward "disadvantaged communities," as defined by each state.

43 The soft path to water refers to the transition away from reliance on large, centralized infrastructure and toward complementary, decentralized facilities and technologies. Soft-path strategies include economic tools such as markets and equitable pricing, inclusive and open decision making, water efficiency technologies, and environmental protection (Gleick 2003).

Green Project Reserve funds can also be used for water efficiency and reuse projects, such as helping communities adapt to reduced water supply availability from drought, wildfires, extreme heat, or water quality degradation from climate change. In Southern California, the Inland Empire Utility Agency received $30 million from the GPR to finance water reuse to bolster supplies against climate change (US EPA 2015b). The funding supported six projects, including the purchase and modification of an existing reservoir, as well as the installation of more than 30,000 feet of pipeline to transport recycled water to customers and recharge groundwater (US EPA 2015b). These projects helped the utility improve its climate resilience by supplementing local water supplies and making their water system operations more efficient (US EPA 2015b). However, these projects did not explicitly address equity nor the needs of frontline communities.

Another federal option for funding water reuse is the Large-Scale Water Recycling Program within the US Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) program. This program provides up to 25% federal cost-sharing for water recycling projects with total costs of no more than $500 million. These projects aim to help communities develop local, drought-resistant water supplies by converting unusable water into a reliable resource, reducing vulnerability to drought and climate change (Grants.gov, n.d.). The program supported priorities from Presidential Executive Orders 14008 and 13985 to tackle the climate crisis and advance racial equity and support for underserved communities. This funding also advanced the J40 Initiative. As of January 20th, 2025, both of these Executive Orders and the J40 Initiative were revoked by the Trump Administration (The White House 2025a).

> Alternative approaches are important strategies for building and enhancing the climate resilience of water supply and water quality and to reduce risks of climate impacts like floods and droughts.

A recent example of a funded WaterSMART Large-Scale Water Recycling Program project is the City of Boise, Idaho's Recycled Water Program. In 2023, the city received $1 million in grants for a feasibility study and project development. To address climate-related impacts and to increase sustainable local water supplies, the city will replenish depleted groundwater supplies with treated water from commercial entities (US Bureau of Reclamation 2023). The facility is projected to treat up to 5 million gallons of water per day and will benefit low-income and underserved communities by creating a climate-resilient water supply (US Bureau of Reclamation 2023; City of Boise 2024).

Water utilities often offer residential and commercial water efficiency rebates or other incentives to help households and businesses replace inefficient fixtures and appliances. For example, the City of Madison, Wisconsin offers bill credits up to $100 for customers who replace high-water-using toilets with EPA WaterSense-rated High-Efficiency Toilet models (City of Madison 2023).[44] Commercial, industrial, and public authority customers are also eligible for and can receive up to 20 rebates per property address (City of Madison 2023). This program is a key part of the water utility's effort

44 WaterSense is a US EPA labeling program for water-efficient products like showerheads, toilets, and sprinkler system controllers. Learn more at epa.gov/watersense.

to protect the deep-well aquifer supplying the city. The Metropolitan Water District of Southern California offers rebates of $40 per toilet when less efficient toilets are replaced with toilets that use 1.1 gallons per flush or less (SoCal Water$mart 2023). Improving water efficiency is a key pillar of Metropolitan Water District's climate adaptation plan (The Metropolitan Water District of Southern California n.d.) However, rebate programs present a barrier for low-income customers who cannot afford to pay the up-front costs before receiving monetary compensation, which can take several months (Clements et al. 2017; Pierce et al. 2021). Some water utilities offer free installation of high-efficiency devices like toilets and clothes washers for income-qualified customers, which can help address the cost barriers of rebates (Cooley, Shimabuku, and DeMyers 2022).

Alternative approaches are important strategies for building and enhancing the climate resilience of water supply and water quality and to reduce risks of climate impacts like floods and droughts. Frontline communities must have funding and financial resources to implement these strategies in their homes, communities, and watersheds. Strategies include:

1. **Increase the amount of funding available through federal and state programs that can be used to design and build alternative approaches to climate resilience;**
2. **Ensure that funding and financing for alternative approaches are accessible and do not have barriers for frontline communities to identify, apply for, and use the assistance;**
3. **Enact policies that ensure frontline communities are receiving an equitable amount of benefits of funding for alternative approaches; and**
4. **Offer programs to incentivize or pay for water efficiency upgrades in households in frontline communities.**

The next attribute will address the need for equitable financial assistance that allows frontline communities to adopt these strategies without them becoming a financial burden, ensuring that these communities can afford these solutions at scale.

8.5 AFFORDABLE CLIMATE-RESILIENT WATER AND SANITATION FOR HOUSEHOLDS

Attribute description: Frontline communities can afford climate-resilient water and sanitation in their homes without compromising their ability to pay for other necessities like food, housing, health care, and transportation.

Water and wastewater affordability is a growing challenge in the US. Although there is no national standard for what proportion water and wastewater bills should be of a household's disposable income, 10% has been suggested as a useful rule of thumb (Teodoro 2018). Estimates using water and wastewater rates from approximately 400 utilities that collectively served 44 million people in the US projected that more than one-third of these households received water and wastewater bills in 2023 that were above 10% of their estimated disposable monthly income (Teodoro and

Thiele 2024).[45] Trends in water and wastewater affordability from this same study indicated that, from 2017 to 2023, affordability worsened for low-income households, especially for those served by the smallest utilities in the sample (utilities with 3,301–10,000 customers). These trends are a major threat to water and sanitation access because in most states households that are unable to pay their monthly water and wastewater bills are not protected from penalties like having their water services shut off or having a lien placed on their property (Holmes et al. 2020). There is also evidence to suggest that utility practices around shutoffs have been racially biased with a disproportionate number of shutoffs for nonpayment occurring in predominantly Black neighborhoods (Vedachalam, Male, and Broaddus 2020).

> Federal- or state-level funding is needed to address increasing affordability challenges and reach customers not currently covered by a utility program.

As climate change alters water quality and quantity and damages and destroys infrastructure, it raises costs, making basic water and sanitation services less affordable, especially for frontline communities and those already struggling to afford them (Pacific Institute and DigDeep 2024). Water and sanitation systems that are unable to access or use federal, state, or private grants and low-interest loans to build climate resilience will become increasingly reliant on rate-payer funds to update and improve their climate resilience. Often, these systems cannot afford needed climate adaptations, leaving their infrastructure and the service they provide vulnerable to increasingly frequent and damaging climate change driven disruptions (Pacific Institute and DigDeep 2024). As discussed in Sections 8.1 and 8.3, in the long term, the cost of inaction is expected to outweigh the cost of proactive climate adaptation efforts. Therefore, water and wastewater utilities that are unable to be proactive will be left with even higher costs over the long run, which ultimately will be passed on to their rate payers or be absorbed by the systems as deferred maintenance and more frequent service disruptions.

Utility financial capability — a utility's ability to pay for the capital and operations costs associated with providing safe and reliable water or wastewater services (J. P. Davis and Teodoro 2014) — is distinct from, but related to, household affordability. As discussed in Section 7.3, water and wastewater utilities that plan better for climate change, including through asset management plans and demand forecasting, will be better able to maintain lower water rates in the long term, therefore keeping water and wastewater more affordable for the households they serve. In this attribute we focus on approaches to supporting households that struggle to pay their water and wastewater bills, which will only increase as climate change drives up the cost of delivering safe, reliable water and sanitation services.

Utilities that serve large populations (>100,000) commonly offer customer assistance programs and other forms of payment relief for customers who meet income or demographic criteria (e.g.

45 For this analysis Teodoro and Thiele used AR_{20}, an affordability ratio of the basic water and wastewater costs as a share of discretionary income at the 20th percentile of household income. They estimated water and wastewater bills assuming a usage of 6,200 gallons per month (31 days) for a single-family household with four people, or about 50 gallons per capita per day. Their sample of water rates did not include rates from utilities that serve less than 3,300 people.

household income 80% less than area median income; older than 65, disabled, etc.).[46] For example, the San Antonio Water Systems Uplift Assistance Program provides a number of affordability benefits to qualifying residential account holders such as no monthly charges for the first 2,000 gallons of water used, an option to set up a payment plan for past-due account balances, removal of charges for "lost" water once leaks are repaired by a licensed plumber, and emergency payment assistance up to two times per year (San Antonio Water System 2022). Leak identification and repair — especially when subsidized and offered without cost to low-income or disabled households — combines the benefits of saving water (critical for places where water stress from drought is increasing) with helping these populations save money. The challenge for utilities is that assistance and leak repair programs are expensive to operate and small or rural utilities serving small, low-income populations are not able to fund these types of programs (National Association of Clean Water Agencies and Moonshot Missions 2021).

> Households with onsite water and sanitation systems are financially responsible for the cost of maintaining and operating those systems or fixing them after a climate disaster, often with little or no outside financial support.

Federal- or state-level funding is needed to address increasing affordability challenges and reach customers not currently covered by a utility program. While no longer available, a temporary federal low-income water assistance program was created in response to the COVID-19 pandemic. The Low-Income Household Water Assistance Program (LIHWAP) ran from 2021 to 2024 and was funded by the American Rescue Plan Act and the Consolidated Appropriations Act of 2021. LIHWAP provided funds to states, territories, and Tribes to help low-income households with water and wastewater bills by reducing charges through public water systems (J. P. Jones and Carpenter 2024). This approach had the potential to help small and rural utilities provide financial assistance to their low-income customers but was not successful in all areas. Some states were unable to disburse the full amount of LIHWAP funds due to complexities with program administration, varying interpretations of eligibility requirements, and limited public awareness of the program (J. P. Jones and Carpenter 2024). Cumulatively, LIHWAP assisted a total of 1.5 million households, helping to prevent 573,000 water disconnections (US Department of Health and Human Services 2024). The four-year implementation of LIHWAP demonstrated that federal funding could support low-income households to pay for water and wastewater costs, but that changes would need to be made to ensure that funds are distributed to all who need them. Overall, the effort demonstrates a potential national-level solution to addressing increasing affordability challenges under a changing climate.

Another way that states are ensuring water access for frontline communities who cannot afford their water bills is by prohibiting water shutoffs during climate emergencies or during specific times of the year. Based on similar programs that prohibit disconnection of households from energy utilities during wintertime, the State of Washington passed a law that protects low-income households from losing water access during extreme heat (Engrossed Substitute House Bill 1329, 2023). This law is

46 Area media income refers to the median income of households within a specified geographic area. Utilities typically use county or state boundaries as the area from which to assess household median income.

a unique example of a state's intent to reduce the risk posed by a climate threat by attempting to ensure that households struggling to pay will be able to access water and electricity during hotter weather. While other examples of similar laws or rules could not be found, 34 states imposed moratoria on water shutoffs in 2020 to help ensure access to water during the COVID-19 pandemic (Zhang, Warner, and Grant 2022). These policies demonstrate that many state governments can intervene to protect water access during emergency events.

Households with onsite water and sanitation systems are financially responsible for the cost of maintaining and operating those systems or fixing them after a climate disaster, often with little or no outside financial support. As described in Section 8.1, some RCAP's regional assistance providers offer loans to income-qualified households to help install new onsite systems, but these do not explicitly address climate resilience. In some regions, nonprofit organizations like DigDeep have provided financial assistance for helping households without running water or adequate plumbing to connect to nearby utilities, as Glenda's story in Section 8.6 demonstrates. However, many more homes need this kind of assistance than existing NGOs can reach.

Water and wastewater affordability is a growing challenge in the US, in part due to climate change impacts that are driving up costs for utilities and causing damage to existing infrastructure. Households that are unable to afford their water or wastewater bills may be at risk of losing access to water or getting a lien placed on their property. Some of the strategies and approaches to supporting affordability and protecting water and sanitation access for frontline communities are:

1. **Create and offer utility customers assistance programs and other affordability interventions like leak detection and repair for income-qualified households;**
2. **Reinstate and fund federal water and wastewater assistance programs that ensure customers of all water and wastewater utilities have access to financial assistance for paying their utility bills;**
3. **Enact laws at the state, local, or federal level that prevent water disconnections during extreme weather or climate events; and**
4. **If financial assistance for water and sanitation access is provided equitably, it will help prevent disconnections and affordability burdens on frontline communities and households as climate change adds costs on service delivery.**

Funding and financing are required for all the work necessary to build and adapt water and sanitation infrastructure, update and improve O&M to support climate resilience, prepare for climate disasters, respond equitably and effectively when they occur, apply alternative approaches to climate resilience in frontline communities, and ensure that water and sanitation remain affordable. While financial assistance is not a silver bullet to advancing equitable, climate-resilient water and sanitation for frontline communities in the US, it is critical for supporting major, necessary infrastructure transformation. It is also important to make funding for disaster preparedness, response, recovery, and disaster insurance equitably accessible, so that frontline communities can prepare for, survive, and recover from the inevitable climate impacts to come. If financial assistance for climate resilience of water and sanitation is provided equitably, it will help prevent future affordability burdens on communities and households already struggling to pay for their access to water and sanitation.

The following case study from Eastern Kentucky provides a real-world example of how a woman in Appalachia worked with DigDeep to overcome affordability and funding barriers to eventually have safe and climate-resilient water access in her home.

8.6 GLENDA'S STORY — WATER AFFORDABILITY IN APPALACHIA[47]

Glenda, a 65-year-old retired nurse from Whitesburg, Kentucky found herself at the intersection of personal vulnerability and infrastructure failure. After a 42-year career in nursing, Glenda was diagnosed with dementia and became a widow, relying on her daughter Whitney for care. Amid these personal challenges, Glenda faced an additional crisis: her well water became unusable.

For months, Glenda's water was cloudy and unreliable, eventually stopping altogether. Her situation exemplifies the vulnerabilities of private well systems, which are common in rural Appalachia but often overlooked in discussions of water infrastructure. These systems are particularly susceptible to climate change impacts, including increased flooding and drought, which can affect water quality and availability.

Despite being merely 60 feet from a main water line, the cost of connecting to the municipal water system was prohibitively expensive for Glenda and Whitney. Initial estimates put the cost at several thousand dollars — an insurmountable sum for a family already struggling with medical expenses and reduced income. This financial barrier highlights the challenges that many rural residents face in accessing public water systems, even when they are close.

Whitney, now Glenda's full-time caregiver, explored various solutions. They invested in a new pump for the well, spending a significant portion of their limited savings, but to no avail. The well remained dry, leaving them reliant on bottled water and the goodwill of neighbors for basic needs like cooking, cleaning, and bathing.

The situation took a toll on Glenda's health and dignity. Tasks that were once simple, like showering or providing water for her dog, became complicated ordeals. For a woman who had spent her career caring for others, the inability to meet her own basic needs was particularly distressing.

In a last-ditch effort, Whitney started a GoFundMe campaign, hoping the community Glenda had served for decades might rally to support her. This move underscores the often-hidden costs of water insecurity and the ways in which communities sometimes must fill the gaps left by inadequate infrastructure and support systems.

DigDeep's Appalachia Water Project learned of Glenda's situation and intervened. They covered the costs of connecting Glenda's home to the municipal water system, a process that involved not just paying fees but also navigating local regulations and coordinating with the water utility, McDowell County Public Service District.

47 This case study was developed through interviews with Glenda and Whitney, as well as project data and follow-up assessments conducted by the DigDeep Appalachia Water Project team.

The impact of this intervention was transformative. Glenda regained the ability to perform essential daily activities independently, allowing her to stay in her home, significantly improving her quality of life, and easing the burden on Whitney. More importantly, it provided peace of mind — the assurance that clean, reliable water would be available at the turn of a tap.

As of 2024, DigDeep's Appalachia Water Project has connected nearly 400 homes to municipal water systems, benefiting approximately 600 individuals. The project not only addresses immediate water access needs but also considers long-term climate resilience. By connecting homes to larger, more robust municipal systems, the project helps ensure that these households will have more stable water access even as climate change impacts local water resources. Municipal systems often have better capacity to implement water conservation measures, upgrade infrastructure, and respond to extreme weather events than individual well systems.

This case study underscores the need for comprehensive approaches to water security that consider not just the physical infrastructure, but also the financial and social support necessary to ensure access. It also highlights the importance of flexibility and responsiveness in water projects, so that they can address unique situations that fall through the cracks of larger infrastructure initiatives. As climate change increases the frequency of extreme weather events that can impact water infrastructure, projects like this that can quickly respond to individual needs become even more crucial.

9. Knowledge and Information

This category of attributes describes how equitable, transparent, accessible integration and application of technical and community knowledges, data, and information are needed to achieve equitable, climate-resilient water and sanitation.

Achieving equitable, climate-resilient water and sanitation fundamentally requires transparent and accessible technical and community knowledges,[48] data, and information for sound decision making (Biagini et al. 2014; WaterAid, Australian Aid, and Water for Women 2021). For climate research and its outputs (in the form of decision-support information and tools) to be usable means that they will serve the needs of frontline communities most affected by climate change (Coen 2021). As such, it is important that the knowledges, data, information, tools, and systems used to monitor climate changes and to communicate climate and water information and risks are credible, salient, legitimate, and accessible to frontline communities (Cash et al. 2003). These include decision support tools, communication tools, data acquisition efforts, digital databases, and remote communication technologies (Biagini et al. 2014).

These sources of knowledge, information, and decision support information and tools must be useful and usable for communities to prepare for what climate change will do to their water and sanitation systems (Lemos, Kirchhoff, and Ramprasad 2012; Dilling and Lemos 2011). Successful partnerships between researchers and communities have often used a co-production approach where local and technical knowledges are utilized in concert to achieve grounded, holistic, polycentric knowledge and information to inform strategies and solutions (Meadow et al. 2015; Lemos and Morehouse 2005). The attributes to address these needs include accessible and usable water and climate data at appropriate temporal and spatial scales; inclusivity in the use of climate data for risk assessments; equitable data and information translation, communication, and dissemination; and the incorporation of local and technical knowledges and ways of knowing.

48 Although “knowledge” is considered a singular, uncountable noun, we intentionally use the plural “knowledges” to indicate that there is no one monolithic knowledge to understand and address complex issues at the nexus of water and climate equity and that problems and solutions to address climate change require many types of knowledges from myriad disciplines and sources, including local and Indigenous knowledges.

9.1 USABLE WATER AND CLIMATE DATA AT APPROPRIATE SCALES FOR COMMUNITIES

Attribute description: Water resource, climate, and other relevant data are at the appropriate temporal and spatial scales and readily accessible to decision makers, water managers, and frontline communities.

The accessibility and usability of water, climate, and related data at appropriate temporal and spatial scales is vital for effective decision making and water resource management. Data that aligns with the specific needs of water managers, utilities, and frontline communities allows for more precise planning, timely responses to emerging issues, and informed policymaking. For instance, accurate climate data on precipitation patterns can enable water managers to better predict droughts, floods, and other extreme weather events, which is crucial for ensuring water security and resilience in the face of climate change (Vogel, McNie, and Behar 2016). Accessible and usable water and climate data serve multiple purposes: it enhances the ability of local governments to prepare for and mitigate disasters, supports equitable distribution of resources, and helps to ensure that the most vulnerable are not left behind. Accessible and usable data also empowers frontline communities — those who are most affected by environmental changes — to advocate for their needs and develop community-driven solutions. The value of such data is underscored by the fact that it enables stakeholders to make decisions based on the most current and relevant information, which is particularly important in the context of climate change, where conditions are rapidly evolving and the consequences of being unprepared can be catastrophic.

Despite the value of accessible data, several barriers hinder the ability of decision makers, water managers, and frontline communities to obtain and utilize it effectively. One of the biggest challenges in ensuring access to water and sanitation is knowing who does not have access and who is at risk of losing access. Existing data or information about household-level access to water and sanitation are limited. There are a few reasons for this: (1) there is not a clearly defined metric for measuring water and sanitation access at the household level, (2) very limited data and information is made available by utilities or state and local governments, and (3) there are limited legal requirements to collect and publish relevant data (Campbell-Ferrari et al. 2024).

One of the biggest challenges in ensuring access to water and sanitation is knowing who does not have access and who is at risk of losing access.

One significant barrier is the fragmentation of data sources. Water and climate data in the US are often housed in disparate federal, state, and local agencies or universities, making it challenging for users to obtain a comprehensive view (US GAO 2004). This issue is compounded by varying data formats, resolutions, and access protocols, which can create additional obstacles, especially for those with limited technical expertise.

Another critical barrier is the lack of data at the scales needed by local decision makers (Cash and Moser 2000). Many datasets are available only at broader spatial scales, such as county, state, or regional levels, which may not be granular enough to inform local decisions. Similarly, temporal scales are often mismatched with the needs of decision makers; for example, climate models may project changes over decades, whereas water managers might require more immediate data for seasonal or annual planning.

Frontline communities in particular face significant barriers to accessing and using relevant data (Fernandez-Bou et al. 2021). These communities often lack the financial and technical resources needed to interpret complex datasets, and they may not have adequate representation in the decision-making processes where data are used. The digital divide further exacerbates this issue, because many frontline communities have limited access to high-speed internet, which is necessary for accessing and analyzing large datasets and essential information for climate adaptation (Granit 2020).

> Potentially useful climate information often goes unused, representing a gap between what scientists understand to be useful and what end users — be they utilities, policymakers, or communities — recognize as usable for decision making.

Potentially useful climate information often goes unused, representing a gap between what scientists understand to be useful and what end users — be they utilities, policymakers, or communities — recognize as usable for decision making (Lemos, Kirchhoff, and Ramprasad 2012). Referencing Stokes' 1997 study, Lemos and co-authors differentiated between "useful" and "usable" climate information that reflects the ways producers and users of scientific information perceive that information. Specifically, they identify a "usability gap" related to fit, interplay, and interaction (Table 11). The "climate information usability gap" refers to the disparity between the information scientists consider valuable and what users perceive as practical for making decisions (Lemos, Kirchhoff, and Ramprasad 2012). Barriers to usability and ways they might be overcome are shown in Table 11.

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TABLE 11. Opportunities to Narrow the Usability Gap and to Increase Inclusion of Climate Information and Products within Social, Economic, and Ecological Management Systems

Usability gap	Barriers	Opportunities to increase likelihood of adopting new information, products, or technologies
Fit for purpose When the information, technology, or tools are suitable for the designated context and culture for which they are intended	• Not accurate or reliable • Not credible, significant, or timely	• Information and products are accurate and reliable; meaningful for their purpose, context, and culture; and timely to inform the matter at hand using the best available information.
	• Not useful or usable	• Products are perceived as useful, valuable, and are "end-user friendly."
	• Excessive uncertainty	• There is ongoing, two-way communication with established and trusted sources. • Products are legitimate and customized for the end-user and context.
Interplay How people and institutions experience and interpret data, information, and products	• Previous negative experiences working with or incorporating data	• New experiences have positive associations (Lemos, Kirchhoff, and Ramprasad 2012).
	• Value of routine, established practices, and local knowledge ("we've always done it this way")[A] • Low or no perceived [climate] risk or a culture of risk aversion[B] • Difficulty incorporating information into existing workflows or frameworks	• Flexibility is built into decision-making procedures (Beller-Simms et al. 2022). • New knowledge is viewed as a tool to mitigate risk rather than something that is risky to use in and of itself. • There is a perception of climate vulnerabilities (new knowledge outweighs the risk). • In response to public pressures or the threat of public outcry.
	• Insufficient human, technical, or financial capacity	• There is increased in-house support or readily available access to external, relevant expertise or technical support (Lemos, Kirchhoff, and Ramprasad 2012). • There is collaboration with boundary organizations, such as universities, private and public firms, and government agencies, that can translate, mediate, and communicate information into usable forms.
	• Legal barriers to incorporating new data • Lack of discretion to make decisions about which data to use, and how	• Linkages and information flows are created between knowledge production and legal support.

Interactive The relationship between information-data- tools and between creators-users	• Not legitimate	• Information and products are formatted, translated, contextualized, and communicated by trusted sources to meet specific user needs under different contexts.
	• Infrequent and one-way communication	• Communication with trusted sources is ongoing and two-way.
	• End-user relationship	• Information and products are co-produced iteratively. • Users are enabled to develop innovative and affordable tools based on their needs.

[A] Similar adherence to established routines and knowledge in the Southwest have resulted in customized climate information being omitted from water system models (Rice, Woodhouse, and Lukas 2009).

[B] Rayner et al. (2006) found many US water resource managers do not incorporate new knowledge because of perceived legal and financial risks of deviating from established procedures.

Source: Modified from Lemos, Kirchhoff, and Ramprasad (2012).

Several initiatives in the US have successfully addressed some of the barriers in Table 11 by improving data accessibility for decision makers, water managers, and frontline communities. One example is the National Drought Mitigation Center's US Drought Monitor (USDM), which provides real-time, easily interpretable data on drought conditions across the country. The USDM's data are accessible at both broad and localized scales, allowing water managers and communities to make informed decisions about water usage, conservation measures, and emergency responses. For example, a partnership between Tribes, agency and academic scientists, and community members at the Wind River Reservation in Wyoming utilized a co-production of knowledge approach to integrate technical data and information with local and Indigenous knowledges to prepare and respond to drought and climate change impacts on water availability for multiple uses (McNeeley 2017; McNeeley et al. 2018; 2020). This resulted in building capacity of the Tribal water managers to use technical drought decision support information and tools such as the USDM and others and to develop the first reservation-wide drought plan (McNeeley et al. 2020). The strategy behind this effort was to provide immediate and ongoing decision-support information, training, tools, and capacity to Tribal water managers, continually engage community members and Tribal Elders, and integrate local values, knowledge, and observations with technical sciences. The project team, which included the Wind River Tribal Engineer's Office, the North Central Climate Adaptation Science Center, the High Plains Regional Climate Center, and the National Drought Mitigation Center, among many other partners, produced quarterly Wind River Reservation Drought and Climate Summaries that were appropriately scaled to the reservation and included local and instrumental observations. These were distributed broadly throughout the reservation and used by water managers, agricultural producers, and other community members.

Another notable initiative is the US Climate Resilience Toolkit, developed through an inter-agency partnership and managed by NOAA. This toolkit provides a wide array of climate data and resources specifically designed to be user-friendly and applicable to local decision-making processes. It includes case studies, planning tools, and a climate explorer that allows users to visualize climate impacts at different scales. The toolkit is particularly valuable for frontline communities because it provides tailored resources that consider local vulnerabilities and resilience strategies. The toolkit provides an Options Database to explore myriad equitable, resilience-building strategies throughout the nation. These are tagged by hazard type and sectors (like water infrastructure (drinking water or stormwater) or critical facilities) with links to related case studies to learn how other utilities and cities are centering equity within climate resilience plans or amending existing plans when found not to be equitable (US Climate Resilience Toolkit, n.d.-b). A couple of relevant examples include Richmond, VA, Seattle, WA, and San Diego, CA.

Through the US Climate Resilience Toolkit Options Database, utilities can access plans, tools, and resilience actions directly. When the city of Richmond, Virginia realized its resilience plan was not equitable across neighborhoods, the Sustainability Office developed a novel tool, the Climate Equity Index. The tool allows the city to document neighborhood vulnerabilities to climate impacts and to determine a best course of actions in response to climate hazards, such as flooding, to increase climate and socially equitable decision making (US Climate Resilience Toolkit 2024c). Seattle, WA's *Preparing for Climate Change* plan addresses the root cause of vulnerabilities by reducing risk and enhancing resilience in frontline communities that are at greater risk and with limited resources to adapt and respond to climate impacts. (Seattle's resilience actions can be downloaded as an Excel spreadsheet.) Also, the detailed Climate Change Hazard Vulnerability Assessments in Appendix B of *Climate Resilient SD,* San Diego's climate adaptation and resilience plan, offers guidance for cities interested in addressing any of the four primary climate change-related hazards, including extreme heat, extreme rainfall and drought, wildfires, and sea level rise.

> Ensuring that water, climate, and related data and information are accessible at appropriate temporal and spatial scales is crucial for effective decision making, particularly in the context of climate change.

The Indigenous Climate Resilience Network (ICRN) is another example of how data accessibility can be tailored to the specific needs of Indigenous communities. The ICRN works to ensure that Indigenous communities in the Northeast, Southeast, and Midwest regions of the US have access to culturally relevant climate data and tools that respect Indigenous knowledge systems. By bridging Western scientific data with Indigenous knowledge, the ICRN empowers Indigenous communities to engage in climate resilience planning that aligns with their values and needs. Multiple other similar Tribal initiatives exist (too many to cover here), such as the Institute for Tribal Environmental Climate Change Professionals (ITEP) Tribes and Climate Change Program, which provides tools, resources, and trainings on climate vulnerability assessments and climate adaptation planning to Tribes throughout the country. ITEP also led the Status of Tribes and Climate Change reports that empowers Tribes by engaging Tribal knowledge holders and scientists and non-Tribal scientists to help ensure that Indigenous knowledges, perspectives, and needs inform the US National Climate Assessment (Status of Tribes and Climate Change Working Group 2021).

Ensuring that water, climate, and related data and information are accessible at appropriate temporal and spatial scales is crucial for effective decision making, particularly in the context of climate change. While there are significant barriers to data accessibility, successful initiatives like the US Drought Monitor, the Climate Resilience Toolkit, and the Indigenous Climate Resilience Network demonstrate the potential for overcoming these challenges. The strategies to make water and climate data and information usable for frontline communities are:

1. **Focus water and climate research and information on community needs and values instead of those of outsiders;**
2. **Make sure that data and tools are scaled appropriately and meaningfully at the community level whenever possible;**
3. **Make data and information free, understandable, and easily accessible;**
4. **Use a co-production approach to ground technical data and information in local knowledge and expertise (more in Section 9.4); and**
5. **Increase access to internal and trusted external support and expertise to increase capacity and overcome technical, legal, and policy barriers.**

By continuing to improve data accessibility and usability, the US can better support water managers, decision makers, and frontline communities in their efforts to build resilience and adapt to changing environmental conditions.

9.2 INCLUSIVITY IN THE USE OF CLIMATE DATA, PROJECTIONS, AND ASSESSMENTS

Attribute description: Climate data and projections are used with the inclusion of frontline communities to inform water and sanitation and water resources risk assessments, planning, management, and development.

There is increasing recognition in the water and sanitation sector that participatory and community-based practices can increase climate resilience by improving monitoring, filling data gaps, and directly remediating water quality issues (Paul et al. 2018; US EPA 2019b). Incorporating frontline communities into these processes is essential for equitable and effective water resource management. The communities that are disproportionately affected by water-related hazards often have unique knowledge of local conditions (Mitchell et al. 2016). For example, involving local communities in data collection and decision making can lead to more accurate assessments of water availability and quality, as well as more effective strategies for adapting to climate change impacts (Makarigakis and Jimenez-Cisneros 2019). Their inclusion helps to ensure that planning and development initiatives consider their specific needs and vulnerabilities, fostering resilience and sustainability.

Furthermore, effective water and sanitation planning benefits from a collaborative co-production approach that includes frontline communities in decision-making processes (B. Taylor et al. 2024). Co-production of knowledge is the "process of producing usable or actionable science through collaboration between scientists and those who use science" (Meadow et al. 2015). This interdisciplinary and iterative process involves building trust, relationships, and communication channels between scientists, stakeholders, and local residents (Roesch-McNally, Gabrielle and Prendeville, Holly R. 2017; Meadow et al. 2015). An outcome of this process is that "new knowledge and new ways of integrating this knowledge into decision making and action" can be produced (Galende-Sánchez and Sorman 2021). Because co-production involves bringing together multiple perspectives at relevant and local scales, it can be used to identify equitable, climate-resilient strategies that are actionable and serve the needs of diverse communities (Roesch-McNally, Gabrielle and Prendeville, Holly R. 2017).

This approach not only enhances the accuracy and relevance of climate projections but also strengthens community resilience by empowering them to participate in solutions that address their water and sanitation needs (Lebu et al. 2024). By integrating climate data with community engagement, stakeholders can develop adaptive strategies that ensure equitable access to clean water and sanitation services while mitigating the impacts of climate change on vulnerable populations (Oates et al. 2014). Thus, inclusive and informed water resource management is essential for building climate resilience and achieving sustainable development goals that prioritize the needs of frontline communities (Grigg 2024).

> Involving local communities in data collection and decision making can lead to more accurate assessments of water availability and quality, as well as more effective strategies for adapting to climate change impacts.

Ensuring that climate data and projections are used inclusively, particularly when involving frontline communities in water and sanitation risk assessments, planning, management, and development, presents several challenges. Some potential barriers include:

1. Data Accessibility and Literacy

Frontline communities often have limited access to climate data and projections. Even when data are available, there may be significant gaps in understanding and interpreting this information (Ford et al. 2016).

2. Technical and Capacity Constraints

Within many frontline communities there is limited technical capacity to analyze, interpret, and apply climate data effectively. This includes a lack of trained personnel and technical tools necessary for effective climate adaptation planning.

Several recent reports and initiatives highlight the limited technical capacity within frontline communities in the US to effectively analyze, interpret, and apply climate data for adaptation planning. These communities often lack trained personnel and essential technical tools, which hampers their ability to engage in climate resilience efforts (Status of Tribes and Climate Change Working Group 2021; US EPA 2021a).

3. Lack of Representation in Decision-Making Processes

Frontline communities are often underrepresented in policy and decision-making processes. This lack of representation can lead to policies and plans that do not adequately address their specific needs and vulnerabilities (Schlosberg and Collins 2014; Whyte 2013).

4. Economic and Resource Constraints

Many frontline communities face economic constraints that limit their capacity to engage with and implement climate projections and data. These constraints can include limited funding, lack of technical resources, and inadequate infrastructure (Berrang-Ford, Ford, and Paterson 2011; Cohen and Waddell 2009).

5. Cultural and Social Barriers

Cultural differences and social barriers can hinder the effective integration of climate data. This includes differing worldviews, priorities, and traditional knowledge systems that are not always aligned with scientific data (McNeeley and Lazrus 2014; McNeeley 2012; Celliers et al. 2021; Nakashima et al., n.d.).

6. Institutional and Governance Challenges

Institutional barriers, such as fragmented governance, lack of coordination between agencies, and insufficient legal frameworks, can impede the integration of climate data in planning and management processes (Adger et al. 2009; Pahl-Wostl 2009).

Addressing these barriers requires comprehensive strategies that enhance community engagement, capacity building, and inclusive governance. Integrating Indigenous or local knowledges with scientific data and ensuring equitable resource distribution are crucial steps toward more resilient and inclusive water and sanitation management in the face of climate change.

Institutional barriers, such as fragmented governance, lack of coordination between agencies, and insufficient legal frameworks, can impede the integration of climate data in planning and management processes.

Citizen science — drawing on the "collective strength and knowledge of the public to gather and analyze data" to answer and address environmental and public health questions — is one inclusive practice through which users can be included in water and sanitation data gathering and monitoring (US EPA 2019b). Volunteer water monitoring programs are a popular type of citizen science within the water sector and can involve residents using standardized techniques and equipment to collect local water resource data (Deutsch and Ruiz-Córdova 2015). This data can then be used for environmental education, waterbody restoration and protection, and advocacy for improved water quality and policy (Deutsch and Ruiz-Córdova 2015). Through citizen science practices, community members can be directly involved in water and sanitation management and monitoring processes and be empowered to build local resilience to climate change (Paul et al. 2018). For instance, citizen science training on water quality testing can provide residents with the skills and credibility to advocate for greater protection of their water sources from pollution (Deutsch and Ruiz-Córdova 2015).

For example, Alabama Water Watch is comprised of resident volunteers who are trained to sample water on a regular basis and upload the data to a database. This data has been used to pinpoint sources of pollution, develop management plans, and document positive remediation (Deutsch and Ruiz-Córdova 2015). The data has also been used to upgrade many stream use classifications, leading to greater legal protections for local water bodies (Deutsch and Ruiz-Córdova 2015). Like much of the country, climate change impacts in Alabama, including increased instances of flooding and drought, can lead to an increase of pollutants in local waterways. As these citizen groups are actively monitoring their local waterways, participating residents are empowered with the skills to capture these changes and advocate for remediation. The long-term success of Alabama Water Watch has been attributed to local level workshops and support, focus on data credibility, and a user-friendly online database (Deutsch and Ruiz-Córdova 2015).

There are several other documented examples in the US where climate data and projections are used to inform water and sanitation and water resources risk assessments, planning, management, and development with the inclusion of frontline communities. Here are a few notable examples:

1. Navajo Nation Drought Contingency Planning

The Navajo Nation has worked with the US Bureau of Reclamation to use climate projections for drought planning and water management. This collaboration includes community input to address water scarcity and ensure the sustainability of water resources for the Navajo people (Navajo Nation Department of Water Resources 2003).

2. New York City Environmental Justice and Climate Resilience Planning

New York City has engaged with frontline communities through initiatives like Adapt NYC. The city uses climate data and projections to assess risks to water resources and infrastructure, working to include vulnerable populations in decision-making processes (New York City Environmental Justice Alliance, n.d.).

3. Los Angeles' Safe, Clean Water Program

Los Angeles County developed the Safe, Clean Water Program, which utilizes climate projections to enhance water quality and supply. The program involves disadvantaged communities in planning and decision-making processes to address their unique water-related challenges (County of Los Angeles 2024).

4. Southeast Florida Regional Climate Change Compact

This compact is a collaborative effort among counties in Southeast Florida to address climate change impacts, including sea level rise and its effects on water resources. The compact involves community engagement, particularly with frontline communities, to create equitable climate resilience planning (Southeast Florida Regional Climate Compact, n.d.).

At the federal level, the Justice40 Initiative aimed to direct 40% of the overall benefits of federal investments in climate and clean energy to disadvantaged communities. This initiative highlighted the challenges these communities face, including limited technical capacity to engage in comprehensive climate adaptation and resilience strategies. Efforts under this initiative included enhancing the availability of technical assistance and knowledge sharing among frontline communities.

These efforts collectively point to the need for increased technical assistance and capacity-building initiatives to empower frontline communities in the US to better manage and adapt to climate challenges (Section 10). These examples highlight the integration of climate data and projections with community engagement to enhance water resource management and resilience, particularly for frontline communities facing the greatest risks. Ways to achieve this include:

1. **Use an end-to-end co-production approach in assessing climate risks to include frontline communities in design, research, and development of decision-support information and tools;**
2. **Apply citizen science as an inclusive strategy for engaging locals in data gathering and monitoring to incorporate local observers and empower communities to build climate resilience;**
3. **Ensure adequate funding for communities to engage in knowledge co-production and sharing; and**
4. **Recognize and address barriers and capacity constraints at the outset of any water and climate risk assessments by providing culturally appropriate community-centered technical assistance.**

All these strategies contribute to inclusive knowledge production and sharing. However, additional steps must be taken to appropriately integrate and utilize different knowledges and ways of knowing.

9.3. INCORPORATION OF LOCAL AND TECHNICAL KNOWLEDGES AND WAYS OF KNOWING

Attribute description: Local, place-based knowledges, Indigenous knowledges, and different ways of knowing and observing are equally respected, supported, and incorporated with technical data and information for equitable, climate-resilient water and sanitation.

In the US, there is an increasing recognition of the importance of integrating diverse forms of knowledge alongside technical data and information. This acknowledgment extends to local, place-based knowledges and Indigenous knowledges, which offer unique perspectives shaped by generations of lived experience and interaction with the environment. Local knowledge refers to insights held by communities about their surroundings, encompassing ecological patterns, weather phenomena, and sustainable practices rooted in direct observation over time (Huntington 2000; McNeeley 2009; McNeeley and Shulski 2011). Similarly, Indigenous knowledges encompass a vast array of understandings passed down through oral traditions, rituals, and practical applications, emphasizing holistic relationships with the natural world (Berkes 2012; Robin Wall Kimmerer 2013). In addressing the imperative of equitable, climate-resilient water and sanitation systems in the US, the integration of local, place-based knowledges and Indigenous knowledges alongside technical data and information holds immense value. These diverse forms of knowledge offer deep insights into ecosystem dynamics, sustainable practices, and community needs that technical data alone may overlook. Recognizing and incorporating these perspectives can lead to more holistic and culturally appropriate solutions that foster community resilience and environmental stewardship (Hill et al. 2020).

In the realm of water and sanitation management in the US, there is a growing recognition of the importance of integrating diverse knowledge systems alongside technical data to achieve equitable and climate-resilient outcomes. Local, place-based knowledges and Indigenous knowledges play crucial roles in this context, offering insights into sustainable water management practices that have evolved over generations within specific environmental and cultural contexts (Berkes 2012; Chief, Meadow, and Whyte 2016; Jantarasami et al. 2018). These knowledges emphasize holistic approaches that consider the interconnectedness of water systems, ecosystems, and community well-being (Robin Wall Kimmerer 2013).

Efforts to incorporate diverse ways of knowing and observing in water and sanitation management are evident in both policy and practice. For instance, collaborations between government agencies, Indigenous communities, and local stakeholders have led to initiatives that integrate traditional ecological knowledge with modern scientific approaches (Cajete 2000) (Box 1). This integration enhances the adaptive capacity of communities to address water-related challenges exacerbated by climate change, such as droughts, flooding, and water quality issues (Berkes 2012; McNeeley 2014).

BOX 1. Blending Traditional Knowledge, Western Science, and Technology: A Holistic Approach to Equitable Climate Resilience in Alaska Native Communities

A program by the Alaska Native Tribal Health Consortium (ANTHC), the Climate Change Health Assessment aimed to address significant gaps in technical capacity by creating a community climate risk assessment program (Brubaker et al. 2011). This provided essential data and multidisciplinary technical expertise to help these communities make informed decisions about climate adaptation strategies. Additionally, the program included comprehensive climate vulnerability analyses with health assessments and engages local communities in identifying and responding to climate-related health impacts. This holistic approach was designed to help communities understand and manage the complex and long-term challenges posed by environmental changes.

Despite climate assessment and adaption efforts by myriad Alaska Native Tribes, organizations, and university and government agency partners, the lack of sufficient community-specific hazard data and the scarcity of technical personnel have been identified as major barriers to adaptation efforts (Alaska Native Tribal Health Consortium 2024). The ANTHC Climate Initiatives seek to address these issues. By providing multidisciplinary technical expertise and essential data, the program supports informed decision-making for strategies such as protection-in-place or relocation, among others. One such effort is the Local Environmental Observer Network, a network of local environmental observers and topic experts who apply traditional knowledge, Western science, and technology to document environmental changes in communities.

Governmental policies and programs can further support the equitable integration of different knowledge systems into water and sanitation management practices. The inclusion of Indigenous consultation processes in water resource planning and decision-making frameworks exemplifies a commitment to recognizing and respecting traditional knowledge systems (Johnson et al. 2016). Such policies and programs aim to empower communities to participate actively in shaping policies and projects that affect their water resources, promoting resilience and sustainability. One example is the US Global Change Research Program and the National Climate Assessment (NCA), established by Congress through the Global Change Research Act of 1990. This has enabled substantive involvement of Indigenous peoples since the mid-1990s in consulting on and authoring portions of the NCA, which has grown over time. Since the third NCA, it has included a dedicated Indigenous-focused chapter. In subsequent NCAs Indigenous authors and expertise were included in other regional and sector chapters.

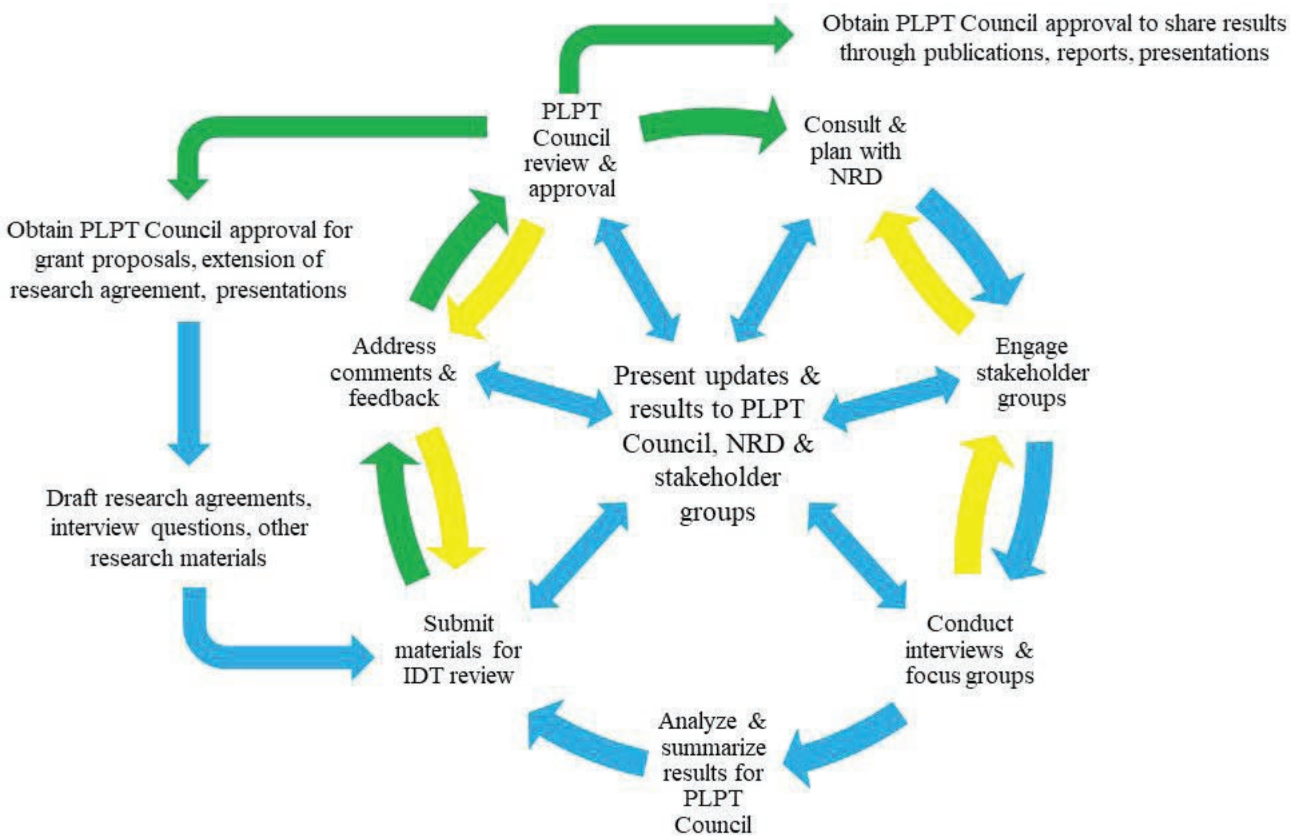
Educational programs and research initiatives also contribute to the incorporation of diverse knowledge systems. Universities and research institutions increasingly emphasize the value of engaging with Indigenous communities and local stakeholders to co-produce knowledge that is relevant and applicable to real-world challenges (Turner, Ignace, and Ignace 2000). Co-production of knowledge and information refers to "the process of producing usable, or actionable, science through collaboration between scientists and those who use science to make policy and management decisions" (Meadow et al. 2015) and inherently implies the integration of local knowledge (Klenk et al. 2017). This approach fosters mutual learning and respect, ensuring that solutions are contextually appropriate and inclusive of diverse perspectives and priorities (Battiste 2002).

> Universities and research institutions increasingly emphasize the value of engaging with Indigenous communities and local stakeholders to co-produce knowledge that is relevant and applicable to real-world challenges.

Several barriers and challenges hinder the full integration of local and Indigenous knowledges in water and sanitation management. These include, for example, institutional biases and bureaucratic processes that prioritize technical expertise over traditional and community-based knowledge systems. Additionally, there can be a lack of mechanisms to validate and integrate these knowledges into formal decision-making frameworks (Berkes 2012). There are significant problems with the extraction of local knowledge without understanding issues of context and culture, power dynamics, and intellectual property (Klenk et al. 2017; David-Chavez and Gavin 2018). If local knowledge is to inform policy, local or Indigenous knowledges cannot be abstracted as "data" divorced from its people, places, and their cultural and historical context and life experiences (Cruikshank 2001). Overcoming these barriers requires fostering collaborative governance structures that actively engage Indigenous communities and local stakeholders in co-designing and co-implementing water and sanitation initiatives.

One strategy to promote the equitable incorporation of diverse knowledges is through establishing partnerships with Indigenous Nations and local communities from project inception. For instance, initiatives like the Native Waters on Arid Lands project (2015–2020) in the Western US successfully integrated traditional ecological knowledge with scientific research to enhance water management practices (McCarthy, Maureen 2022). A research partnership with the Pyramid Lake Tribe Paiute (PLPT) that included Indigenous and non-Indigenous scientists used a participatory, community-engagement approach that centered Indigenous knowledge for understanding climate change impacts on Tribal waters and possible solutions for addressing them (Chew and Chief 2023). They prioritized the Tribe's needs for protecting their knowledge, sovereignty, and community well-being with an approach of "research by and with rather than for or about the PLPT community." Chew and Chief presented a framework for this approach shown in Figure 11.

FIGURE 11. Iterative Process of Community Engagement



Note: NRD refers to the PLPT Natural Resources Department and IDT refers to the PLPT Interdisciplinary Review Team.

Source: Copyright by Chew and Chief 2023. Creative Commons BY 4.0 License. No changes were made.

The PLPT example demonstrates how a decolonized, collaborative, co-production approach can lead to a better understanding of both climate impacts and possible solutions. Moreover, capacity-building programs that empower Indigenous communities to monitor and manage their water resources autonomously can strengthen resilience and sustainability (McNeeley 2017). By fostering mutual respect and collaboration among different knowledge systems, these approaches contribute to more effective and culturally sensitive climate adaptation strategies in water and sanitation infrastructure (Whyte 2018; Berkes 2012; J. Maldonado et al. 2016; Simpson 2004).

In a Pacific Institute, RCAP, Livelihoods Knowledge Exchange Network (LiKEN) collaborative project entitled Water and Climate Equity in Rural Communities in the US, LiKEN used methods in Participatory Action Research (PAR) in Central Appalachian communities for documenting and visualizing participant knowledge, such as collaborative timeline creation, social and power mapping,[49] stakeholder assessments, photovoice,[50] transect walks, among other methods to understand local climate impacts and resilience (B. Taylor et al. 2024). The emphasis on local knowledge and community relationships also lent itself to many new insights and better understandings of what communities really needed. Finally, project participants reflected on relationship building as a central component of the project and embraced the slow speed and complexity of building trust.

Lastly, it is essential in any of these efforts to respect intellectual property and put in place any necessary research protocols or non-disclosure agreements. This helps protect the rights of local or Indigenous knowledge holders against the outside sharing of any potentially harmful or sensitive data or information and prevents exploitative and extractive practices (David-Chavez and Gavin 2018).

Strategies to incorporate different knowledges and ways of knowing include:

1. **Ensure that local experts have consultation and leadership roles in any community research, data gathering, and monitoring efforts;**
2. **Use collaborative, participatory, and/or co-production approaches for equitable incorporation or integration in knowledge creation and sharing; and**
3. **Use appropriate protocols and agreements to protect local knowledge and communities.**

All the attributes in this knowledge and information section so far have focused on equitable approaches to data, information, and knowledge creation, but it is important to also consider the equity issues involved in translating, communicating, and disseminating all of this for frontline communities.

49 Power mapping helps visualize the current power structure to empower citizens for democratic change. It clarifies who aligns with or opposes a common agenda, identifies various types of power, and reveals ways to shift power relationships to achieve shared goals (Livelihoods Knowledge Exchange Network, n.d.).

50 Photovoice is a process where individuals use photos or videos to capture and share their experiences and surroundings. These images, often paired with captions, help convey personal realities to the public and policymakers, inspiring change (Livelihoods Knowledge Exchange Network, n.d.).

9.4 EQUITABLE DATA AND INFORMATION TRANSLATION, COMMUNICATION, AND DISSEMINATION

Attribute description: Data and information collection centers the needs and perspectives of frontline communities and is shared openly and in culturally appropriate formats and languages that are accessible to frontline communities.

There are several factors that contribute to lack of awareness of the water access gap (Roller et al. 2019; Brown et al. 2023). Lack of data and information is a key factor, made worse by the US Census Bureau's recent decision to remove a question from the American Community Survey (ACS) that asked people to check "yes" or "no" if their household contained "a flush toilet." The US Census Bureau itself found that this will lead to undercounting the number of households with incomplete plumbing by approximately 39,000 (Davis Henderson 2019). While small compared to the total number of households in the country, these homes are likely already being left out of decisions related to housing and infrastructure planning and spending, which is what the ACS results primarily are used to inform (US Census Bureau 2022).

> Communicating climate change issues can be politically and culturally fraught, but it may be further complicated by language barriers, different levels of understanding, a lack of accessible resources, a lack of technical-to-lay translation, and inappropriate framing that does not speak to the cultural and socioeconomic context of the audience.

Another factor is the long history of entrenched classism and racism in the US (Brown et al. 2023). Many challenges experienced by low-income and non-White populations in the US, including lack of water and sanitation access, have been historically and systematically unidentified and unrecognized, especially by people in power. In just one example, based on the Indian Health Services (IHS) Home Inventory Tracking System survey in 2020, 52,000 (12.5%) American Indian/Alaska Native homes did not have adequate sanitation, compared to less than 0.4% of the entire US general population (Status of Tribes and Climate Change Working Group 2021; US Census Bureau 2022). Despite these staggering differences, the US Government Accountability Office (GAO) found that federal funding for Tribes and Tribal Nations did not prioritize safe drinking water or wastewater (US GAO 2022).

A third factor contributing to inequitable data and information translation, communication, and dissemination may be related to fear among people who don't want to identify themselves because they are afraid of their children being taken from the home or of deportation due to immigration status. According to a 2016 report, 21 states have laws that stipulate one form of "child neglect" is a lack of running water in the home (P. Jones and Moulton 2016).

There are many frontline communities and their allies that work to raise awareness of this topic (DigDeep 2022; Roller et al. 2019; River Network 2021a; Center for Water Security and Cooperation 2022; US Water Alliance 2017). Much of their work is cited throughout this report. Because of these efforts, more attention is focused on the issue in certain geographic regions, such as on the Navajo Nation, some smaller communities in California's Central Valley, Appalachia, and the Texas colonias, to name a few. These are places where conventional methods for communication are not as effective because of issues like language barriers or distrust of outsiders.

Communicating climate change issues can be politically and culturally fraught, but it may be further complicated by language barriers, different levels of understanding, a lack of accessible resources, a lack of technical-to-lay translation, and inappropriate framing that does not speak to the cultural and socioeconomic context of the audience (Climate XChange, n.d.). This communication gap can result in community members being excluded from decision-making processes and the creation of adaptation measures for their communities. Planners and decision makers also risk missing out on critical local or regional knowledge and observations that can only be gleaned by tapping into the lived experiences of communities, particularly frontline communities and those living with little to no water access.

Climate Xchange is a nonprofit that empowers state and local policymakers, business leaders, and community advocates with information, resources, and networks to make policies that serve the needs of local communities. They identified four key challenges in climate communication:

1. Spatial and temporal dissonance — Some stakeholders may perceive climate change as happening in the future or may downplay its potential severity, but frontline communities know it is already happening and are living with the impacts. Research indicates that images people tend to associate with climate change are abstract or "psychologically distant" with no connection to specific geography, social or temporal characteristics, and often no people (Olano 2022).

2. Language barriers — This may refer to information that is not localized to people's primary language (Diné, Spanish, etc.); information that is not fit for purpose or context and has not been appropriately "translated" to be accessible to its audience; or to the confusion and fatigue around climate-related information and language itself (for example, "climate change" and "global warming"). Language barriers can also refer to the difficulty in understanding complex, technical information about climate change. Without proper translation into lay terms, important information about current and future climate trends will not reach the decision makers who need it.

3. Logical fallacies and a dichotomized perception of climate action — Climate change discourse has often framed climate action as a series of tough choices and tradeoffs requiring sacrifices from the personal to the macroeconomic, and cognitive biases tend to reinforce this idea (Olano 2022). This can create resistance to and skepticism about climate action if people perceive that acting on climate is a zero-sum game that will result in a loss elsewhere in their life.

4. Information deficit model — This refers to the assumption by communicators and decision makers that the public lacks sufficient information and understanding about climate-related issues to act on climate. This can result in a tendency to "accentuate the negative" or a data overload, neither of which has been found to spur people to action and may actually turn people off (Olano 2022).

To enhance communication and knowledge exchange between communities and decision makers and reframe climate and water discussions, four opportunities have been identified:

1. **Present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals, because research suggests that audiences tend to reject fear-based messages** (O'Neill and Nicholson-Cole 2009; Moser and Dilling 2007). By framing challenges in a way that demonstrates how stakeholders' actions can make a difference in managing risks and driving change, the messaging becomes more persuasive and captures the attention of listeners or readers (Moser and Dilling 2004).

2. **Connect climate issues to real-world concerns that people already care about by framing challenges within their local cultural, socioeconomic, or geographic context, as well as aligning with their values and worldviews.** This approach makes climate-related problems more relevant to their daily lives and highlights how climate action can have positive ripple effects in other areas (McNeeley and Lazrus 2014). Following basic communication principles, understanding the audience's interests and concerns, and employing appropriate methods and trusted messengers for climate change messaging are all crucial for building and maintaining trust in relationships, which, in turn, aids in effective communication and response to communication opportunities (Moser and Dilling 2004). For instance, a respected community expert or climate "champion" can act as a reliable point of contact for media outlets, providing well-informed and contextually appropriate insights on these issues.

3. **Embrace uncertainty by focusing on what is known and highlighting scientific consensus, while remaining open to new and improved information.** Reframing uncertainty as risk can make climate challenges feel more tangible and actionable rather than abstract.

4. **Utilize storytelling to effectively convey data, acknowledging and respecting the emotions and psychology of the target audience while validating their experiences.** Storytelling that taps into individual and cultural strengths and values can foster unity and collaboration around climate change issues (Moser and Dilling 2004; 2007).

In conclusion, by valuing and incorporating diverse perspectives and knowledges, barriers can be overcome through inclusive governance structures and collaborative partnerships. Ultimately, these approaches not only enhance the ecological and social resilience of communities but also foster a deeper understanding and respect for the interconnectedness between humans and their environment. Integration of local, place-based knowledges and Indigenous knowledges with technical data and information is crucial for achieving equitable, climate-resilient water and sanitation systems in the US. This, along with accessible and usable water and climate data at appropriate temporal and spatial scales; inclusivity in the use of climate data for risk assessments; equitable data and information translation, communication, and dissemination can help build capacity for frontline communities to achieve equitable, climate-resilient water and sanitation.

10. Capacity Building

This category of attributes describes how water managers, communities, and households are equipped with the technical, managerial, and financial capacity to equitably engage communities and adapt to climate change.

Climate change preparation and response within the context of water and sanitation management requires that people, communities, and institutions have the current and future capacity to effectively manage water and sanitation systems (Ivey et al. 2004). Capacity building here refers to strengthening local leadership, technical, managerial, and financial capabilities of water managers and other water sector professionals, communities, and households to equitably adapt to climate change. This also includes engaging frontline communities in decision-making processes, uplifting community knowledge and voices, and shifting resources and power.

Strategies to build the capacity of water managers and other water sector professionals, communities, and households to equitably adapt to climate change can increase local resilience. This section highlights four attributes of equitable and climate-resilient capacity building strategies for rural water and sanitation systems. They are climate literate, robust, and representative water and sanitation workforce, community empowerment in water and climate-decision-making, capacity to work with interdependent sectors for climate resilience, and technical, managerial, and financial skills for equitable climate resilience. While each of these actions is an important component of capacity building, it is also important that these strategies be implemented in culturally appropriate ways, attuned to local contexts, and co-created with community members and stakeholders to be effective (Ramanadhan et al. 2021).

10.1 CLIMATE-LITERATE, ROBUST, AND REPRESENTATIVE WATER AND SANITATION WORKFORCE

Attribute description: Water and sanitation workforce in frontline communities is climate-literate, robust, and representative of the communities being served.

As climate change accelerates, a robust and climate-literate water and sanitation workforce in frontline communities will be essential to integrating and maintaining equitable climate resilience measures. Robustness of a workforce refers to the ability of staff and other groups responsible for managing, operating, and maintaining climate-resilient water and sanitation systems to perform without failure under a wide range of conditions. In part, this means having enough qualified sector professionals to fill needed positions, especially in small water systems (Rosen et al. 2018). It is equally important that water and sanitation professionals receive the training they need to become climate-literate to equitably prepare for and respond to climate impacts (George, Tan, and Clewett 2016). Climate literacy is defined by the US Global Change Research Program as “an understanding of how the climate system works, how human actions influence climate, and how climate influences people and other parts of the Earth system” (US Global Change Research Program 2024). Further, when water management professionals reflect the communities they serve in their culture and lived experience, they are often better able to meaningfully understand and integrate community needs into climate and water management, planning, and disaster response (US Water Alliance 2017).

As of 2020, the US water and sanitation sectors are experiencing staffing shortages due to low recruitment and retention rates of skilled professionals (US EPA 2020b). Workforce shortages are even more pronounced in rural areas, where competitive incentives often need to be offered to prevent talent from leaving for opportunities in urban environments (Water Resources Alliance 2024; Rural Community Assistance Partnership 2019). Tribal communities have identified a lack of adequate and consistent staff capacity to address climate adaptation priorities as a main barrier to addressing climate change threats (Hasert et al. 2024). To address this barrier, they reported needing funding to hire additional Tribal staff to build the capacity required for adaptation planning and implementation, support for permanent staff positions to minimize disruptions from turnover, hire dedicated climate resilience staff, seek funding to develop affordable housing near Tribal communities, and support staff recruitment and retention (Hasert et al. 2024). Complicating the challenge of staff retention is the reality that about a third of current professionals in the field are set to reach retirement by the end of the decade (US EPA 2020b).

When water management professionals reflect the communities they serve in their culture and lived experience, they are often better able to meaningfully understand and integrate community needs into climate and water management, planning, and disaster response.

Additional capacity barriers within the water and sanitation workforce stem from the fact that water utilities often do not reflect the communities they serve (Vedachalam, Male, and Broaddus 2020). Utility leadership tends to be older, White, and male compared to consumers, which can prevent the utility from understanding community needs and integrating them into management and planning (Vedachalam, Male, and Broaddus 2020). And lastly, knowledge gaps related to climate change and adaptation options are a significant challenge to capacity (Azhoni, Jude, and Holman 2018). Low levels of climate literacy can prevent the implementation of appropriate and equitable climate resilience measures (Lestari, Jatmiko, and Madlazim 2023; Powers, DeWaters, and Dhaniyala 2021; Kolenatý, Kroufek, and Činčera 2022).

Given these challenges, there is an urgent need for education, training, and certification to meet current and future workforce needs (Holodak et al. 2023; Rosen et al. 2018; Flint Water Advisory

Task Force 2016). Education and training aimed at increasing climate literacy through targeted coursework or through existing knowledge networks can bolster water and sanitation managers' ability to prepare for and respond to climate impacts (Kirchhoff 2013; Powers, DeWaters, and Dhaniyala 2021). The Climate Adaptation Partnerships (CAP) Program (formerly Regional Integrated Sciences and Assessments) in the National Oceanic and Atmospheric Administration is an applied research and engagement program that works to expand community capacity to build equitable climate resilience in the US (NOAA 2024a). In one example, the Mid-Atlantic Region CAP worked with regional funders and stakeholders to build an easy-to-use online tool that allows stormwater managers to incorporate climate change into their existing planning, design, and management processes (Miro and Romita Grocholski 2023). The tool helps to update the mathematical formulas commonly used by stormwater engineers to design infrastructure for managing flooding and incorporating climate change impacts to their estimates of precipitation intensity, duration, and frequency. However, this tool was underutilized by practitioners. The regional CAP facilitated an interview process of practitioners and identified additional key elements needed for broader adoption and application. These included the need for practical guidance to select from the range of projected climate changes and scenarios, educational materials for engineers to communicate with the public and decision makers about why climate-informed planning and management are needed, case examples of early adopters of the tool, data and information from trustworthy sources, and support with how to estimate the cost of inaction against the cost of adaptation (Miro and Romita Grocholski 2023).

> Education and training aimed at increasing climate literacy through targeted coursework or through existing knowledge networks can bolster water and sanitation managers' ability to prepare for and respond to climate impacts.

Local workforce development efforts may be able to help fill some of the gaps that are left by a national program like CAP. One advantage of local workforce development programs is that they can be more responsive to local workforce needs and climate challenges (US Water Alliance 2017). In the San Francisco Bay Area, Baywork — a network of 28 water and wastewater agencies — collaborates with the California Community Colleges to align local workforce development needs with programming (Baywork 2021; US Water Alliance 2017a). Baywork offers both its own set of workshops, educational materials and events, online videos, and career development programs, as well as a network and connections with educational institutions, the Department of Labor, workforce development boards, and others that can address their members' needs for improving knowledge, skills, and qualifications. For example, during a major drought in California, Baywork hosted an online panel discussion where local water and wastewater utility staff shared responses and learned from each other (Baywork 2022). The discussion covered topics such as the state of water supplies in different areas, how the drought was affecting local watersheds, water shortage emergency condition declarations, initial amount of recommended or mandatory water restrictions set in place, how those restrictions have changed over time, and other strategies the utilities were employing to address future water supply challenges.

Additional workforce development and training programs that include a focus on both climate and equity are available to water and sanitation professionals. For example, WaterNow Alliance's Emerging Leader Awards Program offers recognition for local water and wastewater utility mid-level staff who are advancing innovative, sustainable, equitable, and climate-resilient water solutions in their communities (Emerson O'Donnell and Koehler 2024). Each awardee receives $1,500 for professional development and is invited to participate in programming focused on building connections and finding solutions to shared challenges in the water and wastewater utility space. The goal of the Emerging Leader program is to foster a more resilient, forward-thinking, and sustainable next generation of water leaders. It prioritizes those from diverse backgrounds who are underrepresented to help ensure water and sanitation workforces are representative of the people they serve (WaterNow Alliance 2024). In 2024, WaterNow brought together two cohorts of their Emerging Leader awardees in Philadelphia to hear from a range of speakers and spark in-depth conversations on multiple topics, including building trust with local communities, equitable engagement, workforce development, and managing water in a changing climate (see Figure 12) (Emerson O'Donnell and Koehler 2024). This program not only celebrates the contributions of water and sanitation professionals but also equips diverse individuals with valuable resources and networking opportunities. By building their capacity to address complex issues around climate and equity, participants are empowered to bring these insights back to their utilities, driving meaningful change.

FIGURE 12. **WaterNow Alliance's 2024 Emerging Leader Convening in Philadelphia**

Source: O'Donnell and Koehler 2024

Pairing workforce development initiatives with climate adaptation education and resources is needed to improve the climate literacy of the workforce. The EPA's Creating Resilient Water Utilities (CRWU)

Initiative offers technical assistance and support tools designed to help water, wastewater, and stormwater practitioners build the climate resilience of their water systems. They deliver lessons on how to use their tools and other resources through workshops, trainings, and webinars to water and wastewater utility staff, local technical assistance providers, government agencies, and other water sector groups (US EPA, OW 2024a). The CRWU Initiative partners with other organizations, agencies, and other programs at EPA to promote adoption of their products and climate resilience strategies more broadly. For example, they partnered with the Water Utility Climate Alliance and NOAA to support a series of workshops focused on enhancing understanding of the capabilities and limitations of climate science, best practices for using climate science in long-term planning, and communication strategies to address institutional barriers and generate engagement around building adaptation and resilience (US EPA, OW 2024a). The CRWU Initiative is designed to support water and wastewater sector professionals that have the time and resources to spend on continuing education, but may not be accessible for staff at small, underresourced water and wastewater systems that are already struggling to operate and maintain their existing systems. The EPA offers training and technical assistance for small, rural, and Tribal drinking water and wastewater systems, but these primarily focus on compliance with federal drinking water and wastewater treatment regulations and do not cover climate resilience or adaptation.

While workforce development and training initiatives can help to improve climate literacy and adaptation skills among existing staff, there is also a need to attract and train new, culturally competent staff to build a more robust and locally representative workforce. Creating local education pipelines for water and sanitation careers can help guide residents into positions where they can represent the needs of their communities. This type of programming can be particularly beneficial in communities where youth have historically faced challenges in accessing workforce opportunities (US Water Alliance 2017). Collaborations can be formed between local labor unions, schools, and utilities to create exposure and access to water and sanitation training and careers (US Water Alliance 2017).

Creating local education pipelines for water and sanitation careers can help guide residents into positions where they can represent the needs of their communities.

For example, the Greater New Orleans Foundation and Greater New Orleans, Inc. partner with local schools to create programming to educate students on water sector career and training opportunities (US Water Alliance 2017). Another example can be found in Alexandria, Virginia, where the local wastewater utility, AlexRenew, partners with a nonprofit that provides “economically disadvantaged” young people with access and exposure to career paths with lifelong potential for economic self-sufficiency (US EPA 2022d). Through this program, the wastewater utility has hosted and paid 10 interns who were directly exposed to the full range of utility jobs, mentored on the technical aspects of different roles, and supported with professional writing and college career planning. These programs help to inform local youth of opportunities for careers in their own water and wastewater utilities, providing the utilities with potential future hires and local youth with a view of economically secure careers, but they do not explicitly address climate change or resilience.

A climate-literate, robust, representative workforce is needed to increase the capacity of water and wastewater systems to equitably adapt and respond to climate change. Strategies to achieve this include:

1. **Take advantage of national and local climate adaptation training and education programs to increase climate literacy in the water and sanitation workforce;**
2. **Provide opportunities for recognition and networking for upcoming utility leaders, especially those from underrepresented backgrounds; and**
3. **Educate students about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.**

There are programs and resources that address workforce challenges, but they do not consistently integrate climate literacy, robustness, and workforce representativeness, potentially leaving gaps in addressing equitable, climate-resilient water and sanitation for frontline communities.

10.2 COMMUNITY EMPOWERMENT IN WATER AND CLIMATE DECISION MAKING

Attribute description: Communities are supported and have increased capacity for inclusive, equitable, and culturally appropriate participation in climate, water, and sanitation decision making.

The meaningful inclusion of communities in climate, water, and sanitation decision making involves careful consideration of culturally appropriate, equitable, and inclusive participation mechanisms. Empowerment of frontline communities in decision making means centering the needs and experiences of community members throughout the process by co-designing, co-planning, and co-implementing strategies. Because frontline communities experience climate impacts first and worst, centering their voices, needs, and lived experiences is critical as climate change accelerates (B. Taylor et al. 2024; Pacific Institute and DigDeep 2024). As such, this attribute focuses on increasing capacity for community inclusion and empowerment in water and sanitation decision making, which is necessary for achieving equitable and climate-resilient outcomes. Complementary to this attribute is the attribute in Section 7.2, which focuses on strategies to center frontline communities in climate, water, and sanitation planning and management.

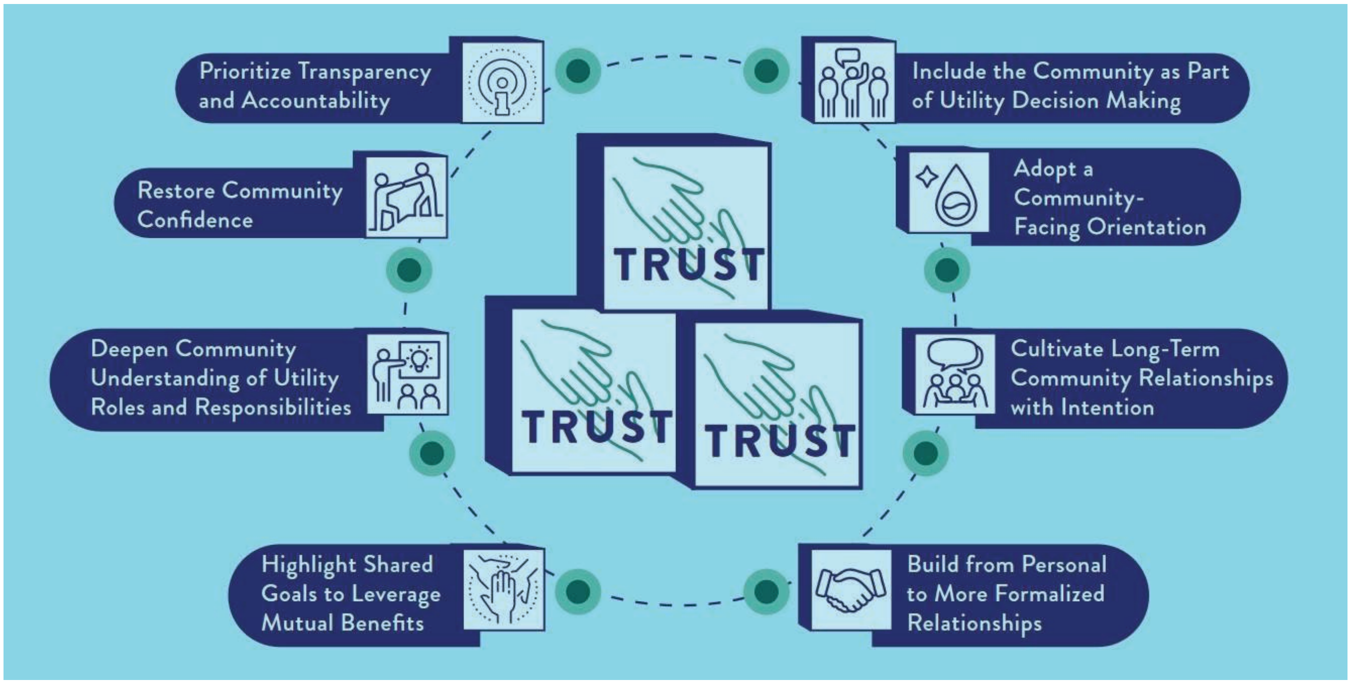
> Empowerment of frontline communities in decision making means centering the needs and experiences of community members throughout the process by co-designing, co-planning, and co-implementing strategies.

A barrier to meaningful community participation in achieving equitable, climate-resilient water and sanitation is when there is a lack of trust between community members and utilities or other providers (Wilson et al. 2023; River Network and WaterNow Alliance 2021; Pierce et al. 2019). The distrust of tap water among Black and Hispanic households has been rising in the US since the lead water crisis in Flint, Michigan in 2014 (Rosinger, Patel, and Weaks 2022; Rutt and Bluwstein 2017). Meehan and co-authors (2020) demonstrated that, in US locations where water is not safe, engineers, water utility staff, and public health officials have lost the trust of those communities. In Appalachia, extreme inequalities, "lack of trust in officials and a public culture of silence and fear, entrenched patterns of violence and intimidation, and a sense of despair and powerlessness to actualize change" make some people reticent to speak publicly about water issues (B. Taylor et al. 2024). In climate change adaptation, a lack of trust in the science or scientists involved in the decision-making process has been found to reduce support for development of and allocation of resources for climate change adaptation strategies (Kettle and Dow 2016).

For Tribal and Indigenous communities, historical and ongoing violations of trust continue to hinder collaboration between US and state government agencies, water utilities, and Tribal communities (McNeeley 2012; Tribal Adaptation Menu Team 2019; Whyte 2020). These gaps in trust can impede progress on equitable climate adaptation.

To overcome barriers in trust between communities and water and wastewater utilities, the River Network and WaterNow Alliance cataloged and analyzed a set of best practices for both community members and utilities in *Building Blocks of Trust: Creating Authentic and Equitable Relationships Between Community Organizations and Water Utilities* (River Network and WaterNow Alliance 2021). The report describes eight building blocks of trust that can be tailored to support culturally appropriate and inclusive decision making for equitably improving capacity and climate resilience for local communities (see Figure 13). For example, one of the case studies in the report outlines how the Santa Cruz Water Department worked to regain public trust after facing intense opposition to a proposed desalination project. The city council formed the Water Supply Advisory Committee (WSAC), composed of 14 community members representing diverse interests. Over 18 months, with the support of a facilitator and technical experts, the WSAC collaboratively developed solutions for long-term water sustainability. By fostering transparency, inclusivity, and community engagement, the water department reestablished trust and achieved broad support for an adaptive process for identifying and selecting water supply projects, setting a precedent for future community-driven processes (River Network and WaterNow Alliance 2021).

FIGURE 13. Building Blocks of Trust from River Network and WaterNow Alliance



Source: River Network and WaterNow Alliance 2021

Decision making for climate resilience and adaptation of water and sanitation systems has historically been top-down, which limits opportunities for meaningful community involvement. Often, community members are asked to weigh in on climate strategies or approaches only after a predetermined set of options have been developed by water utility staff, consultants, or government officials. Abundant research has demonstrated the need to improve procedural justice in climate and water decision making by shifting from top-down approaches to co-creation methods (Solis 2018; 2023; Sultana 2018; Swanson 2021; Tripati et al. 2024; White-Newsome and Slay 2022; Ziervogel et al. 2022). Tripati and co-authors (2024) made the argument that "reform is imperative" to bring equity to US weather, water, and climate services. This reform means "correcting the effects of systemic discrimination" by "changing cultures and sharing power, not solely increasing diversity that often results in bringing BIPOC individuals into hostile environments." A key action is prioritizing community expertise by building close, authentic relationships that support culturally sensitive, timely, and relevant solutions (Tripati et al. 2024). Additionally, providing resources, like monetary stipends, can help build community capacity to participate in water and sanitation management and planning (see Section 7.2 for more information on strategies to advance procedural justice).

One approach to supporting equitable, inclusive, and culturally appropriate participation in water and sanitation involves community-based participatory research (CBPR), where community members collaborate to gather and synthesize their collective wisdom and knowledge to understand how problems affect their community, identify community-specific solutions, and build a case for support (River Network 2022b; Israel et al. 2005). Participatory Action Research (PAR) is a form of CBPR that mobilizes local knowledge while maintaining high standards of scholarly rigor by facilitating inclusive decision making and co-development of products using an iterative and democratic approach (B. Taylor et al. 2024). Co-production of information and products with diverse community members also brings in local knowledge that is often not accessible to outside technical experts (B. Taylor et al. 2024).

In a collaborative project with the Pacific Institute and Rural Community Assistance Partnership (RCAP), Livelihoods Knowledge Exchange Network (LiKEN) used PAR to understand how residents in Harlan and Martin Counties, Kentucky experienced extreme weather in their communities and on their water systems, as well as the distribution of risk, and barriers and openings for building equity and resilience (B. Taylor et al. 2024). Both communities have histories of coal mining, persistent poverty, and water systems impacted by disinvestment and mismanagement, all of which increase the vulnerability of local water and wastewater systems to the impacts of climate change. To understand residents' experiences, LiKEN used multiple PAR methods — including collaborative timeline creation, power mapping, and photovoice — that allowed residents to co-own the knowledge creation process. The information gathered through these methods are being used to help create community-centered climate resilience approaches for water and sanitation systems in these and other communities. These efforts are focused on assets rather than solely on vulnerabilities.[51] For example, to help educate Harlan County residents on the impacts of climate change on their water and sanitation systems, LiKEN developed a tailored Water Resilience Toolkit that included details about water sources, stresses to water and wastewater (including climate impacts), and guidance on preparing for and facing water and climate disasters. Tools like this can empower frontline communities by providing residents with the knowledge needed to actively engage in climate-resilient water and sanitation decision making.

> Grassroots coalitions of community members, community-based organizations, and other nonprofit organizations have also worked to increase community empowerment by advancing policies that improve equitable outcomes in water and sanitation decision making.

Grassroots coalitions of community members, community-based organizations, and other nonprofit organizations have also worked to increase community empowerment by advancing policies that improve equitable outcomes in water and sanitation decision making. For example, in Virginia, water shutoffs during the COVID-19 pandemic garnered significant concern and led to the passage of a human right to water bill (River Network 2021a). Grassroots efforts by organizations like Food and Water Watch and Virginia Interfaith Power & Light played a pivotal role in this achievement, as they shared personal stories of water access with state legislators (H.J. 538, 2021 Spec. Sess. I (Va. 2021); River Network 2021a). This resolution not only recognizes that access to clean water is a human right, but it also acknowledges the importance, in protecting that right, of addressing the impacts of climate change on water quality. It does this by charging state agencies with protecting the state's freshwater resources from climate change, industrial pollution, and from contamination from residents. This example demonstrates how capacity across a coalition of aligned

51 An asset-based approach focuses on a communities strengths, including but not limited to social, economic, and natural assets, rather than only vulnerabilities (B. Taylor et al. 2024).

community groups and organizations can help push for policies that advance equity and climate resilience related to water. (See Bertha's Story (Section 10.5) for a personal account of community engagement to advance equitable and climate-resilient water access in Texas colonias.)

To achieve equitable, climate-resilient water and sanitation, capacity will be needed for improving trust and creating and embedding processes that ensure frontline communities' members are centered in water and climate decision making. Strategies to accomplish this include:

1. **Build trust between communities and water and wastewater utilities by promoting transparency, inclusivity, and community engagement, leveraging tools like the River Network and WaterNow Alliance's Building Blocks of Trust;**
2. **Co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with frontline communities using community-based participatory research and an asset-based approach; and**
3. **Develop coalitions of community members, community-based organizations, and other NGOs to advance community-driven water and sanitation policies.**

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10.3 CAPACITY TO WORK WITH INTERDEPENDENT SECTORS FOR CLIMATE RESILIENCE

Attribute description: People managing water and sanitation systems have the ongoing capacity to coordinate with other people in sectors with whom they are interdependent for climate resilience.

Water and sanitation services exist within a complex and interdependent network of other sectors, including energy, transportation, agriculture, and communications (as discussed in Section 7.5) (University of New Mexico Southwest Environmental Finance Center 2024; US EPA, OW 2022b). For example, the energy sector relies on water for energy production and generation; likewise, water operation facilities and delivery systems require energy (University of New Mexico Southwest Environmental Finance Center 2024). The water and transportation sectors are related as the chemicals and supplies needed for water and sanitation treatment are delivered by truck and rail, and water and sanitation operators rely on transportation networks to get to their place of employment. The agriculture sector relies on the water sector for irrigation, managing waste, and sterilizing equipment (US EPA, OW 2022b). Communication and water are also interrelated as the water sector utilizes telecommunications and information technology for operations, and the communication sector relies on water for equipment cooling and facility operations (University of New Mexico Southwest Environmental Finance Center 2024).

Disruption in one sector can lead to a cascade of effects in other sectors, potentially resulting in widespread consequences for communities. Disruptions to any of these infrastructures can be caused by extreme weather events and are expected to occur more frequently as climate change accelerates (Pacific Institute and DigDeep 2024). For example, the interconnectedness of Texas' energy and water infrastructure created cascading effects after Winter Storm Uri caused major power outages that led to dysfunctions in water services (Glazer et al. 2021). While 14 million residents across Texas went on boil notices, nearly 264,000 went completely without water; this disproportionately affected communities served by small water systems that went, on average, a minimum of three days longer without potable water supplies (Glazer et al. 2021; Wang et al. 2022).

Despite the interconnectivity of water and sanitation with other types of infrastructure and services, each is largely studied, developed, and managed in silos (University of New Mexico Southwest Environmental Finance Center 2024; Szinai et al. 2021). This siloing limits the ability of water and sanitation managers to understand, prepare for, and address how system interconnectivity compounds risks from climate hazards (Szinai et al. 2021). This may be an even greater barrier to overcome for small- and medium-size utilities, which are more challenged for sufficient staff, expertise, and reliable information to manage new risks (University of New Mexico Southwest Environmental Finance Center 2024). Further, climate change risk assessments that do not account for cross-sector interdependencies may miscalculate risks, miss opportunities for adaptation, or lead to maladaptations that increase exposure or socioeconomic vulnerability (Dawson 2015).

For example, the Tyndall Centre used an integrated assessment modelling approach in London to assess interactions across sectors and link climate change risks to broad policies such as city planning. The results of their model indicated that flood-related risks were more sensitive to changes in land use, while heat-related risks were more sensitive to changes in climate (Dawson

2015). This is especially important in frontline communities where issues such as low income and poor air quality exacerbate climate-related risks (Dawson 2015). Frontline communities are also often located in risky areas — such as low-lying areas susceptible to flooding or steep slopes that are difficult to access — and have minimal resources (i.e., finances, time, human resources) to recover from, rebuild, and adapt to climate-related disasters, let alone to strengthen resilience for the future (Oikonomou et al. 2021).

The compounding risks and interdependencies posed by climate change mean that by working together, interdependent sectors can help water and sanitation providers build capacity to prepare for and recover from service interruptions, minimizing negative community impacts (US EPA, OW 2022b). Section 7.5 focused on strategies for coordinated, multi-sector planning and management of water and sanitation. While similar, this attribute focuses on approaches to increase the capacity for coordination, which can lead to enhanced planning, management, investments, and infrastructure and technology decisions for climate-resilient and equitable water and sanitation.

The compounding risks and interdependencies posed by climate change mean that by working together, interdependent sectors can help water and sanitation providers build capacity to prepare for and recover from service interruptions, minimizing negative community impacts.

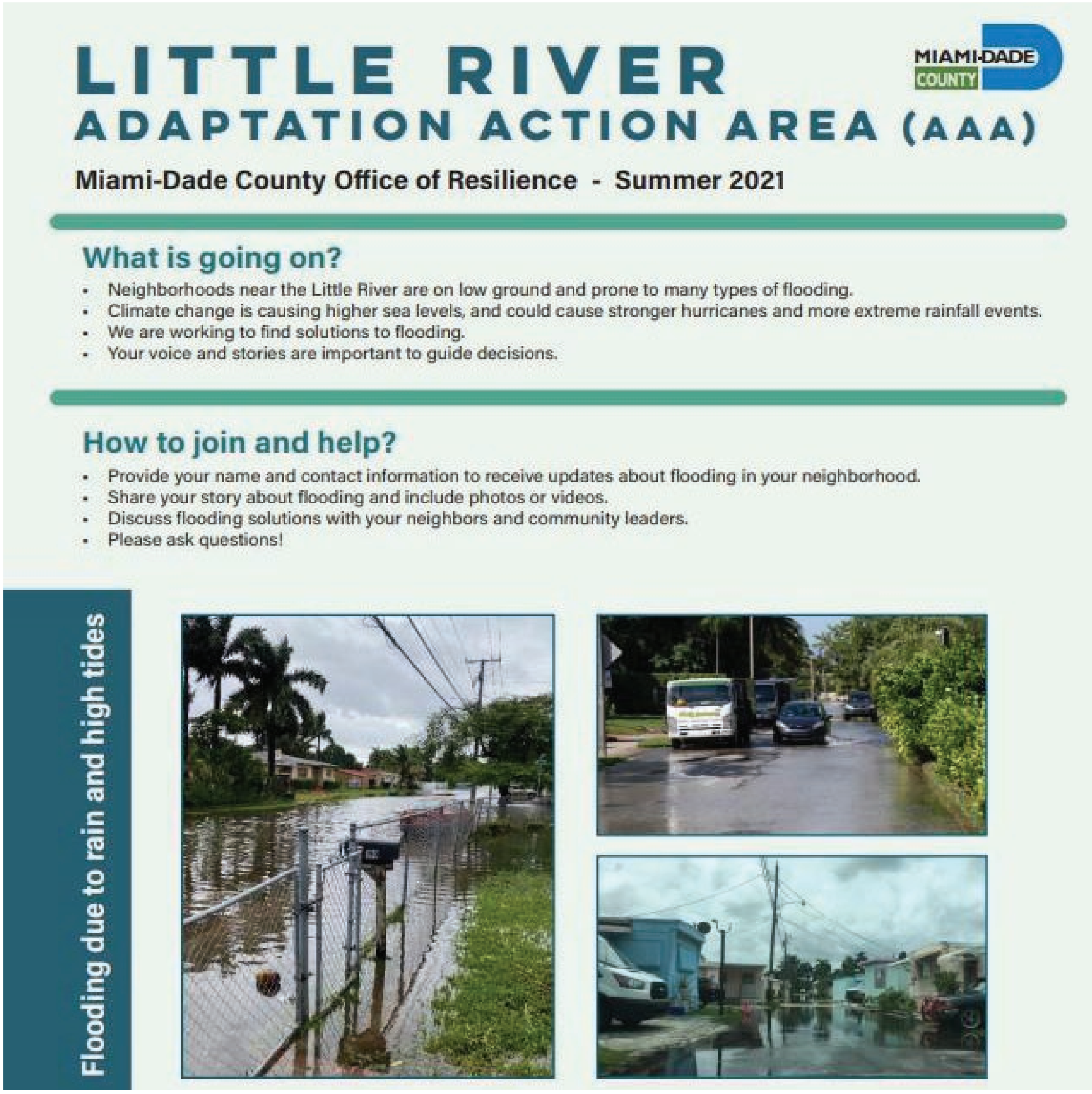
In response to the myriad challenges of working and planning across interdependent sectors, several guides have been created to help water and sanitation managers begin this work. The US EPA's Office of Water (OW) created a Community-Based Water Resilience Guide outlining the interdependencies of multiple sectors, highlighting case studies of disasters in which coordination between sectors was essential (US EPA, OW 2022b). For example, in the aftermath of Hurricane Florence in 2018, local water systems were rendered inoperable, and many residents lost access to clean drinking water (US EPA, OW 2022b). At the same time, over 1,000 roads were closed, leading to a lack of safe or reliable transportation networks, and the North Carolina National Guard was called in to help distribute water and other supplies to affected residents. During the storm, power outages also led to inundation of wastewater treatment plants and sewage spills in several communities (Sound Rivers 2018). More than half a million people were given boil advisories as a result. This climate disaster highlights the interdependency of water, wastewater, energy, and transportation infrastructure, and the importance of enhancing capacity for a coordinated response.

In addition to highlighting such examples, the EPA Community-Based Water Resilience Guide provides templates, checklists, community workshop agendas, and other resources for utility managers, community organizations, and other stakeholders to build capacity for cross-sector collaboration. This is achieved by starting conversations between utilities and communities to identify the actions and resources needed to increase resilience. The resource also includes suggested activities and goals for community workshops, such as identifying methods for integrative water utilities in community planning (see Section 7.5) and facilitating breakout discussions on real or hypothetical climate events.

Similarly, the University of New Mexico's Southwest Environmental Finance Center created a *Water Sector Interdependencies: Small and Medium-Sized System Guidance* document outlining important interdependencies, resources, and partnerships to benefit small and medium-sized utilities that may otherwise lack the staff or resources to build capacity with other sectors (University of New Mexico Southwest Environmental Finance Center 2024). The document also highlights the Water/Wastewater Agency Response Network (WARN), a network of utilities helping other utilities respond to and recover from emergencies (American Water Works Association n.d.). Within WARN, participating utilities can build their capacities through mutual aid. For example, during a snowstorm in Detroit, Oregon, the local water treatment plant lost power, was running on a short-term generator, inaccessible due to high snow berms (American Water Works Association 2008). As a WARN member, Detroit was able to quickly borrow backhoes from another city to clear roads and deliver more propane to the generators, keeping the water plant operable. This is an example of the opportunities available to interdependent utilities to achieve higher levels of capacity and resilience through economies of scale, which may be particularly useful for small, underresourced utilities (Dawson 2015).

Another example of a tool to help build capacity to coordinate across sectors to achieve climate resilience is the Little River Adaptation Action Area in Miami-Dade County, Florida. The initiative is a collaborative and flexible planning tool that addresses climate challenges such as flooding and sewage overflows that are exacerbated by sea level rise and heavy rainfall (Little River Adaptation Action Area, n.d.). Systemic drivers of disparities and financial hardships have made it difficult for households to mitigate these risks. Launched in 2020, the initiative aims to use data to guide capital projects that reduce climate risks, involve community members in climate solutions, and foster cross-sector coordination between governments, residents, and the private sector (Mach et al. 2023). Led by resilience staff in the region and supported by research-practice partnerships, the program emphasizes equitable engagement, environmental stewardship, and integrated responses (Mach et al. 2023). See Figure 14 for an example flyer used by the initiative to educate and engage residents in flooding response, including support for residents to prepare for flooding and opportunities for residents to join the effort. Community workshops and transparent data-sharing have helped identify locally preferred strategies, such as septic-to-sewer conversions and green space expansions, while ongoing monitoring and evaluation ensure the effectiveness and flexibility of these efforts in addressing both immediate and long-term climate risks (Mach et al. 2023). This example highlights how an integrated, community-driven approach can effectively build capacity to address both current and future climate challenges. By establishing a platform for communication, aligning infrastructure investments with equity and resilience objectives, and promoting collaboration across sectors, the Little River Adaptation Action Area initiative showcases how cross-sector coordination can enhance local capacity to effectively respond to climate impacts.

FIGURE 14. Flyer Excerpt Explaining the Adaptation Action Area Initiative



Source: Little River Adaptation Action Area, n.d.

Building capacity to collaborate across interdependent sectors is critical for ensuring climate resilience and equity in water and sanitation systems. Cross-sector coordinating with areas like energy, transportation, and communications not only strengthens the ability to recover from disruptions but also addresses the disproportionate impacts on frontline communities. Key strategies to increase the capacity for cross-sector coordination include:

1. Leverage existing tools and resources, such as the EPA's Community-Based Water Resilience Guide, to understand interdependent sectors and initiate conversations;
2. Foster partnerships between neighboring water and wastewater utilities to provide mutual aid and support to recover from climate disruptions; and
3. Develop local or regional climate adaptation initiatives that foster education, information sharing, and communication across sectors to enhance preparation and response to climate impacts.

10.4 TECHNICAL, MANAGERIAL, AND FINANCIAL SKILLS FOR EQUITABLE CLIMATE RESILIENCE

Attribute description: Water managers are empowered with the technical, managerial, financial (TMF), and leadership skills to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.

The acts of creating, adapting, and maintaining equitable, climate-resilient water and sanitation systems thrive when water managers are empowered with the requisite TMF skills and leadership needed to advance equity and climate resilience in community water and sanitation systems. TMF skills include technical knowledge and implementation, staffing and organization, and revenue efficiency (US EPA, OW 2015c). Achieving and maintaining compliance with national safe drinking water regulations relies on strong TMF skills, making it an important attribute for water systems of all sizes (US EPA, OW 2015c; 2015d). Small and rural water systems can particularly benefit from TMF skills building, as they are more likely to experience barriers that make it harder to comply with safe drinking water regulations (Dobbin, McBride, and Pierce 2023; Statman-Weil, Nanus, and Wilkinson 2020; US EPA, OW 2015c; Vedachalam, Male, and Broaddus 2020). As climate change alters water quantity, quality, and demand, central to equitable climate resilience are TMF skills related to achieving or maintaining Safe Drinking Water Act (SDWA) compliance and affordability (Pacific Institute and DigDeep 2024).

> The acts of creating, adapting, and maintaining equitable, climate-resilient water and sanitation systems thrive when water managers are empowered with the requisite technical, managerial, and financial skills and leadership needed to advance equity and climate resilience in community water and sanitation systems.

Similarly, strong leadership skills are important to advance equitable, climate-resilient water and sanitation. Water and sanitation management are complex processes that require navigating social, cultural, organizational, economic, regulatory, and environmental factors within cross-boundary and multi-stakeholder contexts (International Water Centre n.d.). Navigating this dynamic context, particularly in the face of a changing climate, requires experienced and agile leaders from within the water and sanitation sectors, the community, and beyond so that water and sanitation services are prepared for and equitably responsible to resident needs and system shocks.

Across the US, low levels of TMF skills are a known barrier to the provision of safe drinking water in small and low-income communities (Glade and Ray 2022). These systems may face difficulty hiring experienced staff, conducting rate studies, or investing in and effectively managing physical infrastructure due to low TMF skills (Nylen, Pannu, and Kiparsky 2018). Such challenges make it more difficult to be in compliance with state and federal safe drinking water requirements, as they might not have the TMF skills to respond to these challenges in cost-effective ways (Nylen, Pannu, and Kiparsky 2018).

Insufficient leadership can also pose a significant barrier to developing climate-resilient and equitable water and sanitation management. Traditional leadership development within water management has focused primarily on senior leadership and is linked to slow progress in capacity development (Lincklaen Arriëns and Wehn De Montalvo 2013). This approach may be insufficient to address the complexity, uncertainty, and volatility of today's changing climate, which requires leadership skills such as the ability to reach across organizational, cultural, and geographic boundaries, collaboration, and systems thinking (Van Velsor and Wright 2015; Lincklaen Arriëns and Wehn De Montalvo 2013).

There are documented strategies and solutions to increase the TMF and leadership skills of water and sanitation managers in frontline communities. For example, the state of Mississippi requires TMF training as a capacity development program for all elected or appointed board members of public community water systems, which is linked to high levels of compliance with SDWA rules and regulations across the state (Gasteyer and Taylor 2009). The program is enforced through capacity development inspections that evaluate management factors, including financial records and rate raises (Gasteyer and Taylor 2009).

> Across the US, low levels of technical, managerial, and financial skills are a known barrier to the provision of safe drinking water in small and low-income communities.

Formal and informal social networks can also support TMF skills in rural communities serving Indigenous and underserved populations (Kettle et al. 2023; B. Taylor et al. 2024). These networks help build capacity for water and wastewater managers by providing grant opportunities for climate resilience, supporting planning design and operations, helping to build emergency management capacity, supporting research on innovative approaches to address connections between climate, water, and health, providing post-disaster support, and providing training and information exchange, all of which support the advancement of equitable climate resilience in frontline communities (Kettle et al. 2023).

Physical consolidation that directly connects the infrastructure of two water or wastewater systems — often requiring an ownership transfer, and regionalization approaches such as shared staff, contractual assistance, or shared water resources — have been proposed as solutions to build the TMF skills and climate resilience of small water and sanitation systems (Landes et al. 2020; Vedachalam, Male, and Broaddus 2020). These systems struggle the most with water quality standards, have lower TMF skills and lower capacity to advance equity, and are less able to take advantage of economies of scale (Dobbin, McBride, and Pierce 2023). Consolidation and regionalization can be informal (systems sharing resources outside formal contract), contractually binding, joined through the formation of a separate legal entity, or involve ownership transfer and consolidation (Landes et al. 2020). Consolidation and regionalization are strategies to increase the capacity of small water systems by improving water quality and meeting safe drinking water quality standards, addressing climate vulnerabilities and emergency preparedness, enhancing financial capacity, and sharing expertise and staffing, all of which may bolster the climate resilience of frontline communities (Dobbin, McBride, and Pierce 2023; Landes et al. 2021).

However, consolidation and regionalization are not always seen as desirable solutions at the community level (Glade and Ray 2022; Landes et al. 2021). One reason is that communities of color and low-income communities are underrepresented among consolidated systems calling into question the potential for consolidation to advance equity (Dobbin, McBride, and Pierce 2023). Also, Dobbin and co-authors found that potential gains from economies of scale through consolidation may be limited, underscoring the nuances involved in consolidation and the importance of not taking the promoted benefits of consolidation as blanket statements. However, consolidation remains a tool in a toolbox of potential solutions to build TMF skills in small or underperforming systems to advance equitable climate resilience (Dobbin, McBride, and Pierce 2023; Landes et al. 2021).

Very small systems are more vulnerable to climate-related risks because they typically rely on a single water source, such as groundwater, and it is these same systems that violate the SDWA most frequently (Dobbin, McBride, and Pierce 2023). In California, efforts to improve access to safe drinking water have reduced the number of public water systems statewide by over 3%. These efforts include Senate Bill 88 (2015), which required water systems serving disadvantaged communities to consolidate if they cannot reliably provide safe drinking water, and the Safe and Affordable Drinking Water Program (2019), which encouraged voluntary consolidations (Dobbin, McBride, and Pierce 2023). However, benefits are likely context specific, and more research is needed to better understand and quantify the benefits (Dobbin, McBride, and Pierce 2023).

> A number of programs are designed to advance leadership skills for community leaders and utility professionals to advance climate-resilient water and sanitation.

A number of programs are designed to advance leadership skills for community leaders and utility professionals to advance climate-resilient water and sanitation. One such program is WaterNow Alliance's Emerging Leader Program, which was highlighted in Section 10.1. Additionally, River Network's *Tools for Equitable Climate Resilience: Fostering Community Leadership* features detailed descriptions of other leadership development programs. For example, the Atlanta Watershed Learning Network is a free training program designed to build a diverse learning community equipped with essential social and technical skills. Its goals are to foster resilience to climate change, enhance water quality, reduce flooding, and drive sustainable community impacts in Atlanta (The Watershed Learning Network, n.d.). The training takes place over a six-month period and includes modules covering topics from watershed management to environmental justice, and the participants complete a capstone project to apply their new skills (River Network 2022a). These and other leadership programs can increase the TMF knowledge and capacity of leaders and professionals to assist in decision making and increase resilience to climate hazards.

Other tools, like the asset management resources for small and rural communities shared in Section 7.3, can help water and sanitation managers build the financial skills necessary to maintain financial health in the face of climate change. The US Environmental Protection Agency's Creating Resilient Water Utilities (CRWU) program also provides several TMF-related resources for water managers, including the Climate Resilience Evaluation and Awareness Tool (CREAT), which utilities can use to assess climate-related risks to their systems and identify appropriate adaptations for climate resilience (US EPA 2014a). CREAT includes the following modules:

1. **Climate awareness: provide basic utility information; increase awareness of climate impacts;**
2. **Scenario development: understand utility risk; design scenarios of threats based on climate data;**
3. **Consequences and assets: outline potential consequences; catalog critical assets;**
4. **Adaptation planning: inventory current actions that provide resilience; design adaptation plans; and**
5. **Risk assessment: assess risk from a changing climate; compare risk reduction of adaptation plans.**

The CRWU provides water sector utilities with a multitude of tools, including risk assessment tools such as the Resilient Strategies Guide; links to the NOAA Water Sector Resources; Adaptation Case Studies for Water Utilities; and technical and funding assistance.

Building TMF skills and capacity is important for advancing equitable, climate-resilient water and sanitation, especially for frontline communities. Strategies to accomplish this include the following:

1. **Require TMF trainings for water system board members to support compliance with regulations, such as the Safe Drinking Water Act;**
2. **Establish formal and informal social networks among underserved systems to share information and resources for overcoming capacity challenges and better prepare for climate impacts;**
3. **Consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity; and**
4. **Take advantage of leadership training programs to develop leaders equipped with TMF skills to advance climate-resilient strategies.**

Building water managers' and communities' capacity is essential for achieving equitable and climate-resilient water and sanitation in frontline communities. By fostering leadership, climate-literacy, and representation in the water and sanitation workforce through targeted training, networking, and educational opportunities, water and climate management and planning processes can be made more inclusive and responsive to local needs. Water and wastewater utilities can build trust with communities and prioritize participatory approaches to help ensure frontline communities are empowered to participate in decision making and co-developing climate-resilient strategies. Additionally, building capacity for cross-sector collaboration through partnerships between neighboring utilities, developing local or regional climate adaption initiatives, and using existing resources and tools to spark conversations can help frontline communities be more prepared to respond to climate disruptions to water and sanitation. Finally, investing in technical, managerial, and leadership skills through trainings, formal and informal networks, and consolidation and/or regionalization can equip water and sanitation managers to navigate the complexities of climate challenges. Together, these approaches not only build resilience but also address systemic inequities, laying the groundwork for a more climate-resilient future for frontline communities.

This third case study from a home in a colonia in Texas demonstrates a long-term and ultimately successful effort by a woman and her community to work together to build the capacity to overcome systemic barriers to equitable, climate-resilient water and sanitation access.

10.5 BERTHA'S STORY — CAPACITY BUILDING IN TEXAS COLONIAS[52]

Bertha's story from the Cochran colonia just outside El Paso, Texas, encapsulates the long struggle for basic water access in marginalized communities and the power of persistent advocacy. The Cochran colonia, like many others along the US-Mexico border, developed in a "donut hole" without basic infrastructure, leaving residents without reliable access to water and electricity, despite being surrounded on all sides and just a short distance from fully serviced urban areas.

For decades, Bertha and her family lived without running water in their home. This lack of basic infrastructure had far-reaching implications for their daily lives and long-term well-being. Simple tasks like cooking, cleaning, and personal hygiene became complex challenges requiring careful planning and water conservation. The family relied on a combination of bottled water and sporadic water deliveries, which were both costly and unreliable.

Beyond the day-to-day inconveniences, the absence of water infrastructure posed serious health and safety risks. Bertha lived in constant fear that, with no nearby fire hydrants, a fire could devastate their community. This anxiety was compounded during the hot Texas summers when the risk of fire increased, and the need for water for basic cooling and hydration became even more critical.

Recognizing that their situation was untenable, Bertha, along with other community members, began a campaign of advocacy that would span decades. They organized protests, attended county meetings, and repeatedly pleaded with local officials to extend water services to their community. Their efforts often felt futile, with Bertha recalling that "they never listened to us." This experience of being ignored or dismissed is common among residents of colonias and other marginalized communities, reflecting broader issues of environmental justice and equitable access to basic services.

The community's advocacy efforts faced numerous obstacles. There were jurisdictional disputes between different levels of government about who was responsible for providing services to the colonias. Financial constraints were often cited as a reason for inaction, with officials arguing that extending infrastructure to small, isolated communities was not cost-effective.

Despite these challenges, Bertha and her neighbors persisted. They educated themselves about their rights, built alliances with advocacy organizations, and continued to make their voices heard. Their decades-long fight illustrates the immense effort often required for marginalized communities to secure basic services that others take for granted.

52 This case study was developed through interviews with Bertha and other community members, along with data collected by DigDeep's Colonias Water Project team.

DigDeep's community-led Colonias Water Project began working in the area informed by the community's long-standing advocacy efforts. Working together with local government officials and utility leaders, running water finally came to the Cochran colonia. For Bertha and her neighbors, the completion of the water line construction marked the end of a 30-year fight and the beginning of a new chapter in their lives.

The arrival of running water transformed daily life in the colonia. Families could now cook, clean, and bathe without the constant stress of water scarcity. Children no longer had to ration their water use or miss school to help with water-related chores. The community's health improved as better hygiene became possible, and the ever-present fear of fire diminished. Families are moving back into the community when before, people were struggling to even leave.

Importantly, the newly supplied water is not only ensuring that this community has running water in their homes, but it also enhances the ability of firefighters to access water if needed to fight wildfires and protect their community in emergency situations. This added layer of security is crucial as climate change increases the risk of wildfires in the region.

The project's community-led approach ensures that the infrastructure is tailored to local needs and can be maintained long-term. By incorporating climate resilience into the design, such as using drought-resistant materials and implementing water conservation measures, the project aims to secure water access for these communities even as climate conditions change.

DigDeep's work in this area is made possible through partnerships with several organizations. These include the Adults and Youth United Development Association (AYUDA), a community development organization that helps provide water and wastewater services on the ground; the University of Texas at El Paso, which, through research, supports on the scope of the work needed in each colonia; Horizon Municipal Utility District, which helps expand services to neighboring colonias that are beyond its boundaries; and the El Paso County government, which helps to increase the political will and support for delivering services in the colonias within El Paso County.

This case study underscores the importance of community engagement in water projects. The success of the Colonias Water Project was built on the foundation laid by years of community advocacy. It demonstrates how external interventions can be most effective when they align with and support community-led efforts. Bertha's story is not just about gaining access to water; it's about a community empowering itself to face current challenges and build capacity for the future.

11. Conclusion

Climate change is a threat to everyone in the US. This is especially true for the more than 2 million people in the US who lack running water and sanitation and for the millions more living with insufficient, unsafe, or unaffordable water and sanitation in their homes and communities (Roller et al. 2019). These frontline communities are most at risk from the extreme temperatures, inland flooding, wildfires, droughts, sea level rise, and extreme storms made worse by climate change (Pacific Institute and DigDeep 2024). Frontline communities that lack access to water and sanitation and the attendant risks are inequitably distributed across race and income and have been linked to current and historical patterns of marginalization, disenfranchisement, racism, and colonialism (Roller et al. 2019; Meehan, Jepson, et al. 2020; Mueller and Gasteyer 2021; Status of Tribes and Climate Change Working Group 2021; Ripkey, Waller, and Thompson 2024).

Despite the myriad barriers and challenges in the US, frontline communities are finding ways to achieve equitable, climate-resilient water and sanitation. This report compiles and explores some of the strategies and approaches these communities and their supporters are using to make progress toward this goal.

The strategies and approaches included here are organized within an eight-part framework of the key attributes of equitable, climate-resilient water and sanitation. The eight attribute types include: built infrastructure, technology and innovation, natural infrastructure, management and planning, funding and financing, knowledge and information, capacity building, and law and policy. Herein we covered seven of the eight attribute types in the framework (the eighth focuses on law and policy will be covered in a future report). We define what they mean, explain their importance, summarize barriers and challenges to achieving them, highlight helpful resources and tools, and describe documented examples of strategies and approaches that have been applied in frontline communities. We also include three stories of people and their journeys to secure equitable, climate-resilient water and sanitation in their home.

The report documented the numerous ways frontline communities across the country are making progress toward equitable, climate-resilient water and sanitation. Built infrastructure is being adapted to better withstand the impacts of extreme storms, floods, and drought. Technologies and other innovations are being designed by and deployed in remote, hard-to-reach communities to deliver climate-resilient water and sanitation to homes for the first time. Natural infrastructure strategies are being used to enhance climate resilience of water and sanitation by, for example, helping recharge aquifers and attenuate floodwaters. Water managers and planners are incorporating climate resilience and centering frontline communities in their efforts to deliver equitable, climate-resilient water and sanitation access to all. Frontline communities are overcoming barriers to accessing the financial resources that they need for climate adaptation of water and sanitation or to recover and respond to climate disasters. Climate and water knowledge and information from government agencies, water managers, and climate scientists are being integrated with local, place-based knowledges to ensure frontline communities and people in positions of power and authority can understand and access the data and information they need for decision making. The capacity of water and sanitation systems staff and decision makers is growing to better center the needs of frontline communities, educate and support the water and sanitation sector workforces in improving climate resilience, and build connections with interdependent sectors.

Table 12 summarizes key findings on the more than 100 strategies and approaches documented in this report for achieving equitable, climate-resilient water and sanitation. The strategies and approaches are not for a single audience. Rather they are developed to advance equitable, climate-resilient water and sanitation in the US for frontline communities, their supporters (e.g., community-based organizations or nonprofits), water resource managers, water and wastewater utilities, policy and law makers, and Tribal, federal, state, and local governments. These strategies are a sampling of diverse approaches without prescribing one-size-fits-all solutions.

TABLE 12. Strategies and Approaches to Equitable, Climate-Resilient Water and Sanitation

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
BUILT INFRASTRUCTURE	
Access to water and sanitation infrastructure and services	Initiate and support community-led water and sanitation infrastructure projects with nonprofit organizations and other entities dedicated to closing the water and sanitation access gap.
	Create local programs to connect households and communities with water and sanitation systems at risk from climate impacts to more climate-robust centralized water and/or sanitation systems.
Built infrastructure performing reliably under a range of climate change impacts	Create tools and frameworks for water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure.
	Improve water supply reliability through water reuse, fixing leaks in distribution systems, recharging aquifers (with floodwater where possible), and deepening groundwater wells.
	Consider consolidation through a range of partnership forms to improve supply reliability during climate emergencies.
	Elevate coastal infrastructure to protect infrastructure from sea level rise.
	Adapt infrastructure to be better prepared for wildfire by adding backflow prevention devices on service lines, installing meters with the ability to automatically shut off and keeping plastic infrastructure away from heat sources.
	When necessary, relocate community water stations and other infrastructure to protect them from damage and destruction.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Inclusive and climate-resilient siting, design, and construction	Create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience.
	Change existing or establish new processes and policies for inclusive and equitable siting and design of climate-resilient water and sanitation infrastructure with direct input from frontline communities.
Equitable, climate-resilient operations and maintenance (O&M)	Identify specific O&M tasks that must be performed or adapted to protect infrastructure from climate impacts.
	Put emergency response systems in place to help operators perform necessary actions during climate emergencies.
	Work with technical assistance providers to perform regular O&M to ensure infrastructure remains in good condition to withstand climate disruptions.
	Use materials, trainings, and tools from technical assistance providers and other supporting entities to learn about tasks needed for improving climate resilience.
	Engage directly with frontline communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.
TECHNOLOGY AND INNOVATION	
Sustainable, climate-resilient, and equitably implemented water technologies	Engage with stakeholders, with special attention to local values and cultures, when designing and implementing water and sanitation technologies and innovations.
	Develop respectful partnerships between universities, technology companies, and frontline communities to co-develop technologies tailored to communities' needs.
	Implement knowledge sharing about climate-resilient technologies, especially to communities with unequal access to information.
	Integrate equity-centered frameworks in the planning and design of technologies that consider environmental, economic, and social equities.
Cost-effective water-saving technologies for frontline communities	Develop water efficiency programs tailored to low-income residents to ensure that they benefit from cost-saving technologies.
	Partner with community-based organizations to build trust within frontline communities and enhance participation in tailored low-income water efficiency programs.
	Leverage corporate investments to implement water and cost saving technologies in frontline communities, such as affordable housing complexes.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Sustainable and equitable water and sanitation technologies implemented at the commercial and industrial scale	Establish policies that promote the commercial adoption of water technologies offering broad climate-resilience benefits for communities.
	Build partnerships between water and wastewater utilities and industries to implement large-scale technologies, such as water reuse systems.
	Design and implement commercial and industrial water technologies and innovations collaboratively with nongovernmental organizations (NGOs) and technology companies.
	Utilize existing support programs to scale up the implementation of innovations across commercial and industrial sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies.
Tested and safe water and sanitation technologies	Engage the community during the pilot phase of a new technology to understand local conditions, values, cultures, and needs before widespread implementation.
	Apply a systematic and integrated management approach, such as Integrated Water Resource Management, to prioritize the safe and effective deployment of climate-resilient innovations within the intricate framework of water and sanitation systems.
NATURAL INFRASTRUCTURE	
Constraints for natural infrastructure (NI) implementation removed	Create integrated NI management plans to coordinate knowledge and information exchange, planning, and management across departments, sectors, and jurisdictions.
	Implement policies to overcome constraints to equitable NI project outcomes.
	Form strong partnerships, coalitions, and interdisciplinary working groups to address conflicts and build NI project support and consensus.
	Use innovative and diverse funding solutions appropriate to the local context.
Centering communities in NI planning	Clearly define justice and equity in NI projects.
	Ensure communities experiencing injustice have a say throughout the planning process using two-way communication.
	Incorporate transparency, trust building, and mutual learning in community engagement.
	Partner with trusted local institutions to engage hard-to-reach groups.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
NI projects proactively removing displacement risks	Utilize and adapt existing toolkits to identify local risk factors for displacement and to evaluate the strength of anti-displacement strategies.
	Implement locally appropriate and feasible anti-gentrification and displacement policies prior to project construction.
	Co-create equity scorecards with residents and other stakeholders to evaluate how well an NI project mitigates gentrification and displacement.
NI benefits valued for achieving equitable climate resilience	Utilize comprehensive valuation models that center climate resilience, human and ecological well-being, and impacts for multiple sectors and stakeholders.
	Incorporate equity-centered guidelines alongside valuation models to understand the distribution of tradeoffs and benefits for frontline communities.
	Incorporate non-market-based valuations and recommendations that center equity.
MANAGEMENT AND PLANNING	
Source water protections incorporated into water, sanitation, and climate plans and programs	Use remediation projects as an opportunity to implement NI that protects source water quality for frontline communities.
	Include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security.
	Collaborate with frontline communities, scientists, and managers to co-produce tools, plans, and programs that safeguard source water.
	Integrate education, awareness, and support for private well water quality testing into management frameworks.
Frontline communities centered in climate, water, and sanitation planning and management	Begin with a visioning stage to incorporate frontline communities' insights into climate-resilient water and sanitation planning from the outset.
	Integrate community-based organizations into climate adaptation and water and sanitation planning and management efforts to improve the representation of marginalized groups.
	Foster collaborative research partnerships that act as boundary organizations, connecting frontline communities with regional and national planning efforts while developing locally tailored resources for self-reliance.
	Provide financial resources, such as stipends, to empower individuals and communities to meaningfully engage in management and planning processes.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Water and sanitation providers financially sound in the face of climate change	Include asset management in long-term planning that takes into consideration climate change impacts to water and wastewater infrastructure.
	Conduct demand forecasting to help ensure that future water demand projections account for both climate change scenarios and efficiency initiatives.
	Employ proactive rate setting to prevent reactive rate increases that could render water and sanitation services unaffordable for frontline communities.
Water and sanitation systems prepared for climate disasters and inequitable impacts	Develop emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for frontline communities.
	Include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected.
	Incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for frontline communities.
	Participate in trainings and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions.
	Integrate resilience hubs into climate, water, and sanitation planning and management to strengthen community resilience and social equity after climate disasters.
Cross-sectoral coordination to achieve equitable, climate-resilient water and sanitation	Align management and planning structures strategically, using frameworks like Integrated Water Resource Management and One Water as foundations for equitable, resilient practices.
	Include interagency working groups in climate, water, and sanitation plans to clarify sector roles in climate disruption responses, establish coordinated technical assistance programs for frontline communities, and promote climate resilience and equity.
	Integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together.
	Participate in specialized trainings and exercises to learn how to address climate impacts on frontline communities equitably and collaboratively across sectors.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness	Involve community members and community-based organizations in the design and implementation of monitoring frameworks to promote inclusive, attainable, and locally informed processes.
	Allocate a specific budget for monitoring and evaluation when designing programs and plans to ensure that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives.
	Use equity-focused indicators to track climate resilience outcomes of water and sanitation plans and programs effectively across communities.
	Apply monitoring and evaluation to both new initiatives and existing practices to comprehensively address systemic inequities and enhance accountability.
FUNDING AND FINANCING	
Funding and financing for climate-resilient water and sanitation infrastructure	Increase the amount of funding available through federal and state programs, including the Clean Water State Revolving Fund (CWSRF) and Drinking Water State Revolving Fund (DWSRF), that can be used to build and adapt climate-resilient water and sanitation infrastructure.
	Ensure that funding and financing are accessible and do not have barriers for frontline communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure.
	Enact policies that ensure frontline communities are receiving an equitable amount of benefits from climate and infrastructure funding.
	Implement technical assistance programs to address barriers experienced by frontline communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure.
	Offer programs to help construct climate-resilient, decentralized water and sanitation infrastructure and/or to connect homes and communities with decentralized infrastructure to more climate-robust centralized systems.
Funding and assistance for climate-resilient O&M	Create and fund federal and state grant programs that explicitly name climate resilience and O&M as funding priorities for water and sanitation systems.
	Offer O&M as an activity available through technical assistance providers.
	Fund and train technical assistance providers on climate-resilient O&M.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Funding and financing for climate disaster preparedness, mitigation, response, and restoration of water and sanitation	Increase funding available through federal community preparedness and climate hazard mitigation programs and expand access to these programs for frontline communities.
	Expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities.
	Ensure that climate disaster response and recovery efforts do not exacerbate or increase wealth inequality.
	Fill gaps in government aid with local efforts by grassroots coalitions and NGOs to create local financing options and climate disaster recovery.
	Provide households at risk of sewer backups or damage to their onsite water or sanitation systems with insurance and funding assistance to recover from climate disasters.
Funding and financing for alternative approaches to equitable, climate-resilient water and sanitation	Increase the amount of funding available through federal and state programs that can be used to design and build alternative approaches to climate resilience.
	Ensure that funding and financing for alternative approaches are accessible and do not have barriers for frontline communities to identify, apply for, and use the assistance.
	Enact policies that ensure frontline communities are receiving an equitable amount of benefits of funding for alternative approaches.
	Offer programs to incentivize or pay for water efficiency upgrades in households in frontline communities.
Affordable climate-resilient water and sanitation and households	Create and offer utility customers assistance programs and other affordability interventions like leak detection and repair for income-qualified households.
	Reinstate and fund federal water and wastewater assistance programs that ensure customers of all water and wastewater utilities have access to financial assistance for paying their utility bills.
	Enact laws at the state, local, or federal level that prevent water disconnections during extreme weather or climate events.
KNOWLEDGE AND INFORMATION	
Usable water and climate data at appropriate scales for communities	Focus water and climate research and information on community needs and values instead of those of outsiders.
	Make sure data and tools are scaled appropriately and meaningfully at the community level whenever possible.
	Make data and information free, understandable, and easily accessible.
	Use a co-production approach to ground technical data and information in local knowledge and expertise.
	Increase access to internal and trusted external support and expertise to increase capacity and overcome technical, legal, and policy barriers.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Inclusivity in the use of data, projections, and assessments	Use an end-to-end co-production approach in assessing climate risks to include frontline communities in design, research, and development of decision-support information and tools.
	Apply citizen science as an inclusive strategy for engaging locals in data gathering and monitoring to incorporate local observers and empower communities to build climate resilience.
	Ensure adequate funding for communities to engage in knowledge co-production and sharing.
	Recognize and address barriers and capacity constraints at the outset of any water and climate risk assessments by providing culturally appropriate community-centered technical assistance.
Incorporation of local and technical knowledges and ways of knowing	Ensure that local experts have consultation and leadership roles in any community research, data gathering, and monitoring efforts.
	Use collaborative, participatory, and/or co-production approaches for equitable incorporation or integration in knowledge creation and sharing.
	Use appropriate protocols and agreements to protect local knowledge and communities.
Equitable data and information translation, communication, and dissemination	Present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals, because research suggests that audiences tend to reject fear-based messages.
	Connect climate issues to real-world concerns people already care about, by framing challenges within their local cultural, socioeconomic, or geographic context, as well as aligning with their values and worldviews.
	Embrace uncertainty by focusing on what is known and highlighting scientific consensus, while remaining open to new and improved information.
	Utilize storytelling to effectively convey data, acknowledging and respecting the emotions and psychology of the target audience while validating their experiences.
CAPACITY BUILDING	
Climate-literate, robust, and representative water and sanitation workforce	Take advantage of national and local climate adaptation training and education programs to increase climate literacy in the water and sanitation workforce.
	Provide opportunities for recognition and networking for upcoming utility leaders, especially those from underrepresented backgrounds.
	Educate students about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Community empowerment in water and climate decision making	Build trust between communities and water and wastewater utilities by promoting transparency, inclusivity, and community engagement, leveraging tools like the River Network and WaterNow Alliance's Building Blocks of Trust.
	Co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with frontline communities using community-based participatory research and an asset-based approach.
	Develop coalitions of community members, community-based organizations, and other NGOs to advance community-driven water and sanitation policies.
Capacity to work with interdependent sectors for climate resilience	Leverage existing tools and resources, such as the Environmental Protection Agency's (EPA) Community-Based Water Resilience Guide, to understand interdependent sectors and initiate conversations.
	Foster partnerships between neighboring water and wastewater utilities to provide mutual aid and support to recover from climate disruptions.
	Develop local or regional climate adaptation initiatives that foster education, information sharing, and communication across sectors to enhance preparation and response to climate impacts.
Technical, managerial, and financial skills (TMF) for equitable climate resilience	Require TMF trainings for water system board members to support compliance with regulations, such as the Safe Drinking Water Act.
	Establish formal and informal social networks among underserved systems to share information and resources for overcoming capacity challenges and better prepare for climate impacts.
	Consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity.
	Take advantage of leadership training programs to develop leaders equipped with TMF skills to advance climate-resilient strategies.

While this report provides ample evidence that there is a large and growing body of knowledge surrounding water, climate change, and equity, through our research we identify several gaps that indicate a need for future research and documentation at the nexus of water, climate, and equity. These include:

- A comprehensive evaluation of climate adaptation plans for a focus on equitable, climate-resilient water and sanitation.
- Research on the effectiveness of climate-resilience tools and frameworks from nonprofit and government agencies.
- An evaluation of the outcomes from programs designed to connect homes with decentralized, onsite water or sanitation systems that are at risk of failure due to climate change to centralized systems.

- Quantification and understanding of the types and distributions of benefits achieved from consolidation of water systems, recognizing they are likely case and context dependent. How effective are physical consolidations for increasing climate resilience and creating equitable outcomes for frontline communities?
- Identify O&M activities of both centralized and decentralized water and wastewater systems that help prepare for and prevent disruption or destruction of these systems from climate events.
- How are technologies for commercial, agricultural, and industrial water users affecting climate-resilience and equity for frontline communities? Furthermore, guidance is needed for the equitable implementation of climate-resilient water and sanitation technologies in these sectors.
- Research on the intersection of utility financial capability, household affordability, and climate resilience. There is an especially significant dearth of guidance relevant for small, underserved utilities and communities on this topic.
- Research on the equity and climate-resilience outcomes of monitoring and evaluating climate plans, especially related to water and sanitation.
- There are examples of frontline communities that have been able to obtain climate resilience funding for water and sanitation, but very little documentation of how they overcame the myriad barriers to obtaining and using that funding.
- The Bipartisan Infrastructure Law allowed for additional subsidization up to 49% using SRFs. Has this resulted in additional SRF funds being distributed as grants?
- Are there more states like Washington that are issuing protections for water access for households unable to afford their water bills during climate events?

The solutions to achieving equitable, climate-resilient water and sanitation in the US will always be place-based and context-dependent, so there is no one-size-fits-all. We hope that the examples, lessons learned, and tools reviewed in this report can support advancement toward this goal in many different locations, but this will require careful consideration of how to adapt strategies and approaches from one place to another. More work is needed to better understand and support the needs of and opportunities for frontline communities to build and maintain climate-resilient water and sanitation systems. Until those needs and opportunities are at the center of efforts to adapt and transform water and sanitation in the face of climate change, the solutions will fall short of achieving the goal of equitable, climate-resilient water and sanitation. We present this report as a knowledge foundation upon which to build practical solutions for the communities who need them the most.

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Disclaimer: During the publication of this report in early 2025, the federal administration changed from the Biden to Trump administration. In this process, many of the federal websites and reports that were cited in this report were removed from their respective agency websites. The authors attempted to replace these links with archived versions of the resources, wherever possible, however, there remain some that are no longer accessible, and additional links may become broken after publication. Efforts to catalog the past agency websites are underway and can be used by readers to try to find any of the missing citations herein.

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