

Strategies for Resilient Rural Water and Sanitation in the United States



SEPTEMBER 2025

Strategies for Resilient Rural Water and Sanitation in the United States

AUTHORS

Shannon M. McNeeley, Pacific Institute

Rebecca Anderson, Pacific Institute

Rachel Will, Pacific Institute

Morgan Shimabuku, Pacific Institute

Jessica Dery, Pacific Institute

CONTRIBUTING AUTHOR

Alexandra Campbell-Ferrari, Center for Water Security and Cooperation

SUGGESTED CITATION

McNeeley, Shannon M., Rebecca Anderson, Rachel Will, Morgan Shimabuku, and Jessica Dery, 2025. Strategies for Resilient Rural Water and Sanitation in the United States, Pacific Institute, Oakland, CA, <https://pacinst.org/publication/strategies-for-resilient-rural-water-and-sanitation-in-the-us/>



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 THE AUTHORS

Shannon McNeeley

Shannon McNeeley is the Associate Director, Water and Climate Equity at the Pacific Institute. 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.

Rebecca Anderson

Rebecca "Becky" Anderson is a Research Specialist 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 Research Specialist 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.

Morgan Shimabuku

Morgan Shimabuku is a Senior Research Specialist 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.

Jessica Dery

Jessica Dery is a Senior 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.

ACKNOWLEDGEMENTS

Thank you to Betsy Taylor, Deborah Thompson, and Madison Mooney from Livelihoods Knowledge Exchange Network, as well as Laura Landes, Lena Schlichting, and Victoria Harrington, for their essential input, feedback, and guidance throughout the development of this report. We also thank Heather Cooley, Morgan Shimabuku, and Matthew Bennett for their thoughtful reviews and support in finalizing the report. All conclusions expressed herein, and any errors or omissions, are those of the authors. We acknowledge the partnership of the Pacific Institute Communications and Outreach team to launch this work and ensure it reaches key decision makers, audiences, and other levers of change toward the goal of building a more resilient world. This work was generously supported by the BHP Foundation.

DEDICATION

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

Water is life.





Table of Contents

Glossary	5
Summary	9
1. Preface	29
2. Introduction	31
3. A Framework for Achieving Equitable, Climate-Resilient Water and Sanitation for Rural Water Systems	37
3.1. Characteristics of the Strategies and Approaches to Equitable, Climate-Resilient Water and Sanitation in Rural Communities	38
3.2. Resources, Tools, and Case Examples	38
4. Built Infrastructure	40
4.1. Access to Water and Sanitation Infrastructure and Services	41
4.2. Reliable Performance Under a Range of Climate Change Impacts	46
4.3. Inclusive and Climate-Resilient Siting, Design, and Construction	52
4.4. Equitable, Climate-Resilient Operations and Maintenance	55
4.5. Built Infrastructure Summary	60
5. Technology and Innovation	61
5.1. Equitably Implemented Climate-Resilient Water and Sanitation Technologies	63
5.2. Cost-Effective Water-Saving Technologies for Rural Communities	67
5.3. Sustainable, Equitable Water and Sanitation Technologies for Large-Scale Water Users & Operations	69
5.4. Tested and Safe Water and Sanitation Technologies	74
6. Natural Infrastructure	78
6.1. Removing Constraints for Natural Infrastructure Implementation	80
6.2. Centering Communities in Natural Infrastructure Planning	84
6.3. Natural Infrastructure Projects Proactively Remove Displacement Risks	88
6.4. Natural Infrastructure Benefits Valued for Achieving Equitable Climate Resilience	91
6.5. Natural Infrastructure Summary	95
7. Management and Planning	96
7.1. Source Water Protections Incorporated into Water, Sanitation, and Climate Plans and Programs	97
7.2. Rural Communities Centered in Climate, Water, and Sanitation Planning and Management	101
7.3. Rural Water and Sanitation Providers Financially Sound in the Face of Climate Change	105
7.4. Rural Water and Sanitation Systems Prepared for Climate Disasters and Inequitable Impacts	108
7.5. Cross-Sectoral Coordination to Achieve Equitable, Climate-Resilient Water and Sanitation	112
7.6. Equitable, Climate-Resilient Planning and Management Continually Monitored and Evaluated for Effectiveness	116
7.7. Management and Planning Summary	118
8. Funding and Financing	119
8.1. Funding and Financing for Capital Investments in Climate-Resilient Rural Water and Sanitation Infrastructure	120
8.2. Funding and Assistance for Climate-Resilient Operations and Maintenance	124
8.3. Funding, Financing, and Disaster Insurance for Climate Disruptions	128
8.4. Funding and Financing for Alternative Approaches to Equitable, Climate-Resilient Water and Sanitation	133
8.5. Affordable Climate-Resilient Water and Sanitation for Rural Households	137
8.6. Funding and Financing Summary	141

9. Knowledge and Information	142
9.1. Usable Water and Climate Data at Appropriate Scales for Rural Communities	144
9.2. Inclusivity in the Use of Climate Data, Projections, and Assessments	147
9.3. Incorporation of Local and Technical Knowledges and Ways of Knowing	151
9.4. Equitable Data and Information Translation, Communication, and Dissemination	154
9.5. Knowledge and Information Summary	159
10. Capacity Building	160
10.1. Climate-Literate and Robust Water and Sanitation Workforce Representative of Their Community	161
10.2. Rural Community Empowerment in Water, Climate, and Sanitation Decision Making	165
10.3. Capacity to Work with Interdependent Sectors for Climate Resilience	168
10.5. Capacity Building Summary	174
11. Law and Policy	175
11.1 Laws Set Structural Standards to Ensure Reliability of Services	176
11.2 Laws Protect Rights, Allocations, and Uses of Water for Domestic Purposes	177
11.3 The Law Requires Water and Wastewater Utilities, as well as State and Local Governments, to Conduct Climate Resilience Planning	178
11.4 Laws Require Creation, Collection, and Publication of Data and Information	180
11.5 Laws Appropriate and Equitably Distribute Funding for Water and Wastewater Services and Infrastructure	181
11.6 Laws Are Enforceable and Enforced	182
11.7. Law and Policy Summary	183
12. Conclusion	184
Appendix: Tables of Identified Attributes, Strategies, and Approaches per Category	187
References	201



Figures and Tables

FIGURE S1. Framework for Achieving Equitable, Climate-Resilient Water and Sanitation	10
TABLE S1. Built Infrastructure Attributes	11
TABLE S2. Technology and Innovation Attributes	13
TABLE S3. Natural Infrastructure Attributes	15
TABLE S4. Management and Planning Attributes	17
TABLE S5. Funding and Financing Attributes	20
TABLE S6. Knowledge and Information Attributes	23
TABLE S7. Capacity Building Attributes	25
TABLE S8. Law and Policy Attributes	27
FIGURE 1. Comparison of Federal Rural Definitions by Rural Health Information Hub	32
FIGURE 2. Water and Climate Resilience Framework	35
FIGURE 3. Framework Categories for Achieving Equitable, Climate-Resilient Water and Sanitation	37
FIGURE 4. Households with Incomplete Plumbing as Reported by the 2014–2018 American Community Survey	42
FIGURE 5. Destruction Caused by 2018 Camp Fire in California	49
FIGURE 6. Kentucky WARN Program Webpage	57
FIGURE 7. A Diné College Student Demonstrates Use of the Water Filtration System	64
FIGURE 8. Estimated Total Water Withdrawals by Category and State in 2020	69
FIGURE 9. BluBox Mobile Wastewater Unit in Town of Spruce Pine	72
FIGURE 10. Portable Alternative Sanitation System	75
FIGURE 11. Development of an Inter-Agency Work Group	82
FIGURE 12. Interactive, Augmented Reality Sandbox Used by Pennsylvania’s Rural Water Association’s Source Water Protection Specialist to Educate the Public.	98
FIGURE 13. Word Cloud of Community Priorities from Community Visioning Workshop	102
FIGURE 14. Snapshot of Harlan County Water Resilience Toolkit	109
FIGURE 15. Conceptual Alaska Environmental Threat Implementation Framework	113
FIGURE 16. Portion of Rural Economic Action Plan Grant Program Fact Sheet.	122
FIGURE 17. Portion of Circuit Rider Program Flyer	126
FIGURE 18. Montgomery County RainScapes Program	136
FIGURE 19. United Way 211.org Webpage	138
FIGURE 20. Example Map from US Drought Monitor	145
FIGURE 21. Photos from Exploratory Scenario Planning for Water Resilient Agriculture	155
FIGURE 22. WaterNow Alliance’s 2024 Emerging Leader Convening in Philadelphia	162
FIGURE 23. Building Blocks of Trust from River Network and WaterNow Alliance	166
TABLE 1. Strategies, Resources, and Case Examples for Rural Access to Water and Sanitation Infrastructure and Services	45
TABLE 2. Strategies, Resources, and Case Examples for Climate-Resilient Rural Water and Sanitation Infrastructure	51
TABLE 4. Strategies, Resources, and Case Examples for Equitable and Climate-Resilient Operation and Maintenance for Rural Water and Sanitation Infrastructure	59
TABLE 5. Examples of Water and Sanitation Technologies by Category and the Corresponding Resilience Outcomes	62
TABLE 6. Strategies, Resources, and Case Examples for Equitably Implemented Water and Sanitation Technologies for Rural Communities.	66

TABLE 7. Strategies, Resources, and Case Examples for Cost-Effective Water Saving Technologies for Rural Communities.	68
TABLE 8. Strategies, Resources, and Case Examples for Water and Sanitation Technologies for Large-Scale Water Users in Rural Areas	73
TABLE 9. Strategies, Resources, and Case Examples for Tested and Safe Water and Sanitation Technologies for Rural Communities	76
TABLE 10. Strategies, Resources, and Case Examples to Address Constraints to Natural Infrastructure Implementation in Rural Communities	83
TABLE 11. Strategies, Resources, and Case Examples for Centering Rural Communities and Equity in Natural Infrastructure Planning	87
TABLE 12. Anti-Displacement Strategies for Communities Undergoing Green Gentrification	89
TABLE 14. Strategies, Resources, and Case Examples for Natural Infrastructure Valuation	94
TABLE 15. Strategies, Resources, and Case Examples for Equitable, Climate-resilient Rural Source Water Protection	100
TABLE 16. Strategies, Resources, and Case Examples for Centering Rural Communities in Climate, Water, and Sanitation Management and Planning	104
TABLE 17. Strategies, Resources, and Case Examples for Rural Water and Sanitation System Financial Health and Climate Resilience	107
TABLE 18. Strategies, Resources, and Case Examples to Prepare Rural Water and Sanitation Systems and Communities for Climate Disasters	111
TABLE 19. Strategies, Resources, and Case Examples for Rural Water and Sanitation Cross-Sector Planning and Management	115
TABLE 20. Strategies, Resources, and Case Examples for Rural Monitoring and Evaluation of Climate, Water, and Sanitation Plans and Programs	118
TABLE 21. Strategies, Resources, and Case Examples for Funding and Financing for Climate-Resilient Water and Sanitation Infrastructure in Rural Communities	123
TABLE 22. Strategies, Resources, and Case Examples for Funding and Assistance for Climate-Resilient Water and Sanitation Operations and Maintenance	127
TABLE 23. Strategies, Resources, and Case Examples for Funding Climate Disaster Preparedness, Response, and Restoration, and for Disaster Insurance for Rural Communities	132
TABLE 24. Strategies, Resources, and Case Examples for Advancing NBS, GI, Water Efficiency, and Water Reuse to Enhance Rural Water and Wastewater System Resilience	137
TABLE 25. Strategies, Resources, and Case Examples to Help Rural Households Afford Water and Wastewater	140
TABLE 26. Strategies, Resources, and Case Examples for Usable Water and Climate Data for Rural Communities	147
TABLE 27. Strategies, Resources, and Case Examples for Inclusiveness in the Use of Climate Data, Projections, and Assessments in Rural Climate, Water and Sanitation	150
TABLE 28. Strategies, Resources, and Case Examples to Incorporate Local and Diverse Knowledges with Technical Data and Information in Climate, Water, and Sanitation Management	153
TABLE 29. Strategies, Resource, and Case Examples to Achieve Equitable Data and Information Translation, Communication, and Dissemination in Rural Climate, Water, and Sanitation	158
TABLE 30. Strategies, Resources, and Case Examples for Climate-Literate, Robust, and Representative Water and Sanitation Workforce in Rural Communities	164
TABLE 31. Strategies, Resources, and Case Examples for Empowerment in Water and Climate Decision Making for Rural Communities	167
TABLE 32. Strategies, Resources, and Case Examples for Capacity to Work with Interdependent Sectors for Climate Resilience in Rural Communities	170
TABLE 33. Strategies, Resources, and Case Examples for Technical, Managerial, and Financial Skills for Equitable Climate Resilience in Rural Communities	173
TABLE A1. Built Infrastructure Strategies	187
TABLE A2. Technology and Innovation Strategies	189
TABLE A3. Natural Infrastructure Strategies	191
TABLE A4. Management and Planning Strategies	192
TABLE A5. Funding and Financing Strategies	194
TABLE A6. Knowledge and Information Strategies	196
TABLE A7. Capacity Building Strategies	198
TABLE A8. Law and Policy Attributes	199

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 (Feinstein 2018; Teodoro 2019).

Asset-based: Values and methods that foreground the positive resources and attributes of a community to affirm and build on the strength, knowledge, and perspective of those directly affected by the problem being addressed (Taylor et al. 2024). The goal is to avoid a focus on negative images of what communities lack and need. This approach is closely related to methods of “appreciative inquiry” that focus first on strengths to build a cascade of transformational changes based on cumulative successes. This avoids an emphasis on community problems that can trap the work within negative and disempowering frameworks.

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).

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).

Climate resilience: Defined by the US National Climate Assessment as the capacity of interconnected social, economic, and ecological systems to cope with a climate change event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure. Climate resilience is a subset of resilience against climate-induced or climate-related impacts.

Community water system: A community water system is defined by the federal Safe Drinking Water Act as a public water system that serves "at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents" (42 U.S.C. § 300f(15)).

Cross-sector: Refers to work that bridges the sectors of community, civil society organizations (differentiated from “community” by referring to incorporated organizations, vs. the more informal and embedded process of community), specialists (scholars, technical experts, knowledgeable practitioners, and community experts), and governments (including Indigenous governments). Depending on the project needs, it can also include businesses/corporations, philanthropy, and other sectors.

Decentralized water system: Decentralized water systems are those that are not connected to interconnected, centralized systems that rely on water treatment facilities and pumping stations or wastewater treatment plants. Here, decentralized systems primarily refer to private wells and onsite septic systems (Pacific Institute and DigDeep 2024; Campbell-Ferrari et al. 2024).

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 Safe Drinking Water Act (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.

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, Native Hawaiians, Pacific and Caribbean Islanders, state-recognized Tribes, and unrecognized Tribes and peoples. More specific terms will be used where the Tribal 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): 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, 2020; 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).

Operation and Maintenance (O&M): Ongoing activities required to run and maintain water and sanitation systems, as well as routine checks, repairs, and adjustments of equipment to optimize efficiency and reliability. Climate-resilient O&M includes standard practices as well as additional measures specifically designed to address the impacts of climate change on infrastructure.

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 (US EPA 2015d).

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 safe disposal of human waste and wastewater treatment (CDC Foundation, n.d.).

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 2015b).

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 so that 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 resilience: The ability of water systems to function so that nature and people, especially the most vulnerable, thrive under shocks, stresses, and change (Pacific Institute 2021).

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

Many rural communities across the United States face persistent challenges in accessing safe, affordable, and reliable water and sanitation. In some rural areas, households lack running water or basic plumbing, while others rely on systems that do not consistently meet health and safety standards. As described in [Water and Climate Equity in Rural Water Systems in the United States](#), climate change further exacerbates these disparities, with rising temperatures, droughts, floods, wildfires, and sea level rise threatening rural water and sanitation infrastructure (Taylor et al. 2024; Pacific Institute and DigDeep 2024). These challenges not only hinder efforts to expand access but also increase the risk of backsliding, where climate disruptions cause communities to lose previously secured water services (Pacific Institute and DigDeep 2024; Roller et al. 2019).¹

In defining “rural” for this report, we take an inclusive approach to recognize the wide range of communities and contexts this term can encompass. Our focus is on rural water and sanitation systems in the US, which are typically small in scale and often serve fewer than 10,000 people. These may include either centralized or decentralized systems, such as private wells and septic systems. Rural water systems frequently contend with limited funding, aging infrastructure, and capacity constraints that can hinder their ability to consistently provide safe and reliable services.

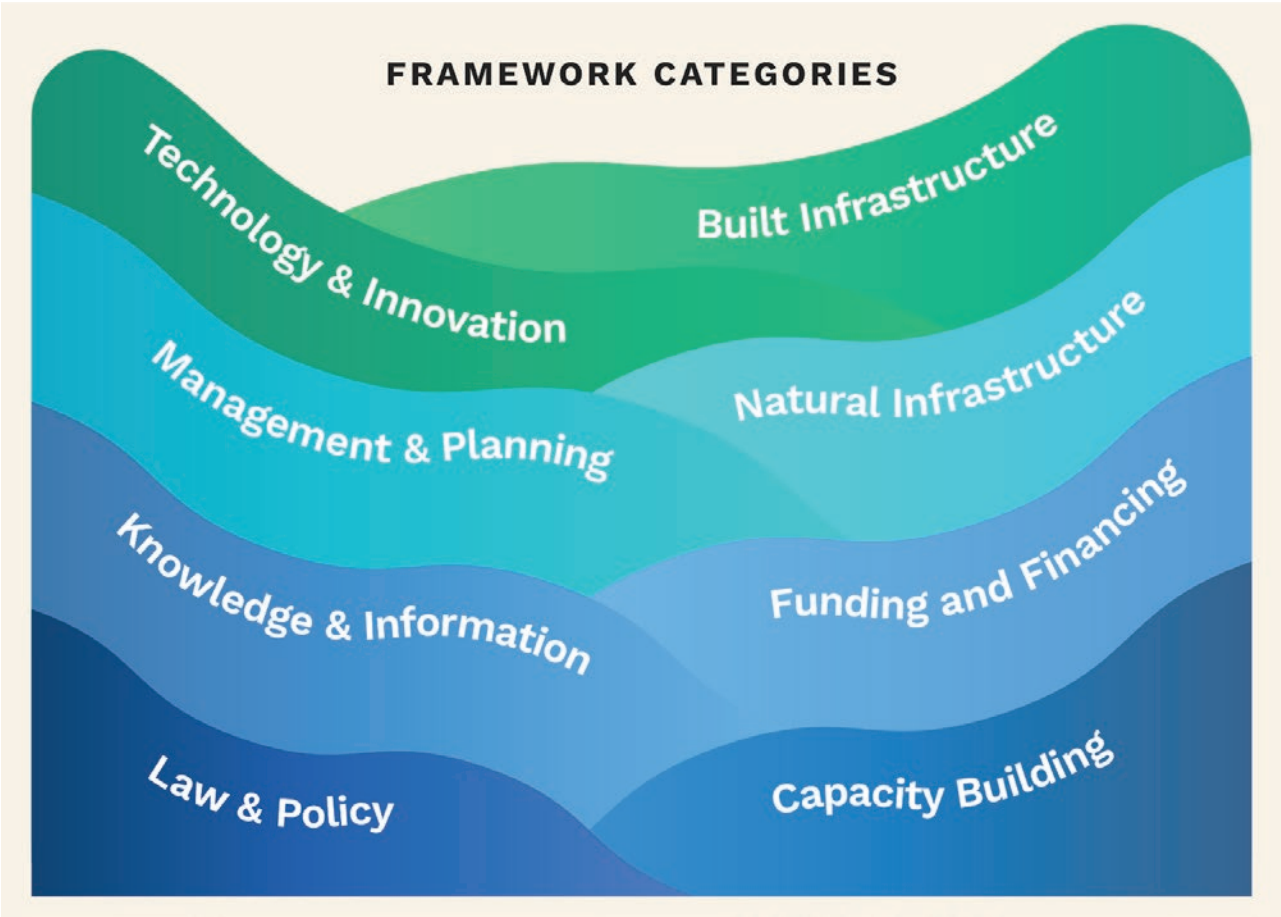
In spite of the obstacles, rural communities are leaning on their strengths and assets to create equitable, climate-resilient water and sanitation (Taylor et al. 2024). This report identifies strategies and approaches that address systemic inequities and increasing climate change impacts on rural water and sanitation systems. To do this, we asked three questions:

1. What is equitable, climate-resilient rural water and sanitation?
2. What are the characteristics or attributes of equitable, climate-resilient water and sanitation in rural communities?
3. What are the strategies and approaches rural communities are taking to achieve this?

¹ Initial use of the term backsliding in the water sector comes from the Clean Water Act (CWA), 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, 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.

To answer these questions, we built upon a framework developed in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025). Through a review of the literature, government and NGO reports, and online tools, as well as direct input from practitioners, the framework identifies eight categories of equitable, climate-resilient water and sanitation. These include built infrastructure, natural infrastructure (NI), technology and innovation, management and planning, funding and financing, knowledge and information, capacity building, and law and policy (see Figure S1). Within each category, we identified key attributes of equitable, climate-resilient water and sanitation along with documented strategies for achieving them. For this report, we reassessed the previously identified attributes and strategies by McNeeley and co-authors for applicability in rural communities. We then refined and updated them to better align with the unique characteristics, challenges, and opportunities in rural places. Here we present 37 attributes and over 130 strategies for equitable, climate-resilient rural water and sanitation in the US.²

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



Source: McNeeley et al. 2025

² The Law and Policy category differs from the rest of the report because this is a higher-level review of the laws and policies relevant to the provision of drinking water and sanitation in rural contexts. A forthcoming report on the law and policy strategies will be published in the fall of 2025. Therefore, in this report, this section does not go into detail on the strategies, resources, tools, and rural case examples as are found in the rest of the report.

Here we summarize the key findings on the 130+ strategies for equitable, climate-resilient rural water and sanitation across eight categories of the report. See the full report for details on case examples and resources for each attribute.

BUILT INFRASTRUCTURE

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

TABLE S1. Built Infrastructure Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Access to water and sanitation infrastructure and services	Rural communities have access to drinking water and sanitation infrastructure and services that allow them to perform basic tasks and maintain personal hygiene in their homes.
Reliable performance under a range of climate change impacts	Built infrastructure performs reliably under a wide range of climate conditions to deliver safe, sufficient, and acceptable water and sanitation for rural 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 to center rural community values and needs.
Equitable, climate-resilient operations and maintenance (O&M)	The O&M of water and sanitation improve climate resilience and facilitate equitable outcomes for rural communities.

Strategies to enhance access to water and sanitation infrastructure services include:

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 in rural areas.
2. Create programs to connect rural households and communities with water and sanitation systems at risk from climate impacts to more climate-robust centralized water and/or sanitation systems.

Strategies to help ensure built infrastructure performs reliably under a range of climate impacts include:

1. Create and utilize tools and frameworks for rural water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure.
2. Improve rural water reliability through water reuse, water efficiency, 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. Update and/or elevate centralized and decentralized water and wastewater infrastructure to protect it from sea level rise and inland flooding.
5. Adapt rural 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.
6. When necessary, relocate rural community water stations and other infrastructure to protect them from damage and destruction.

Strategies for inclusive and climate-resilient siting, design, and construction of rural water and sanitation infrastructure include:

1. Create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience.
2. Incorporate direct input from rural communities when siting and designing climate-resilient water and sanitation.

Strategies for equitable, climate-resilient operations and maintenance (O&M) of rural water and sanitation infrastructure include:

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 so that rural 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 O&M tasks needed for improving climate resilience.
5. Engage directly with rural communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.

Expanding access to safe, reliable, and climate-resilient water and sanitation infrastructure is essential for ensuring rural communities can meet basic daily needs and adapt to the growing challenges of climate change. Built infrastructure in rural settings, like dams, water distribution systems, and treatment plants must be adapted so that they can reliably function under an increasingly broad range of climatic conditions and disruptions. Through these efforts, the engineers, contractors, utilities, and other agencies that lead the siting, design, and construction processes need to ensure that water and sanitation infrastructure is climate resilient. To do so equitably requires the inclusion and centering of rural 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 rural communities.

TECHNOLOGY AND INNOVATION

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

TABLE S2. Technology and Innovation Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Equitably implemented climate-resilient water and sanitation technologies	Sustainable, climate-resilient rural 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 rural communities	Water fixture upgrades, water-saving appliances, and other water-saving technologies are equitably installed to save water and reduce cost burden on utility bills of rural households.
Sustainable, equitable water and sanitation technologies for large-scale water users and operations	Sustainable water-use and sanitation technologies are implemented for large-scale water users and operations, like commercial and industrial users, and increase equity and climate resilience for rural communities.
Tested and safe water and sanitation technologies	New, innovative climate-resilient water technologies are tested and evaluated to help ensure dependability and safety for rural communities.

Strategies for sustainable, climate-resilient, and equitably implemented water technologies include:

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

Strategies for cost-effective, water-saving technologies for rural communities include:

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

Strategies for sustainable and equitable water and sanitation technologies implemented at the commercial and industrial scale include:

1. Establish laws and policies that promote the large-scale adoption of water technologies, offering broad climate-resilience benefits for rural communities.
2. Utilize existing support programs to scale up the implementation of innovations across sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies.
3. Utilize water and wastewater technologies to close gaps in access to services after climate disruptions.
4. Design and pilot large-scale water technologies and innovations collaboratively with nongovernmental organizations (NGOs) and technology companies.

Strategies to implement tested and safe water and sanitation technologies include:

1. Engage the community during the pilot phase of a new technology to understand local conditions, values, cultures, and needs before widespread implementation.
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 rural communities. However, 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 rural communities. Strategies like robust stakeholder engagement, equity-centered frameworks, and partnerships are important to ensure that rural communities benefit from technology and innovations. In addition, water efficiency and reuse technologies can reduce costs for rural communities, although challenges like high upfront costs persist. In addition, large-scale water users and operations have a major role in advancing equity and resilience by adopting technologies that reduce water demand and improve water quality for rural communities. This can be facilitated through relevant policies, partnerships, and support programs. Finally, the effective deployment of these innovations requires a deep understanding of rural contexts and a systematic planning approach to avoid maladaptation.

NATURAL INFRASTRUCTURE

This category describes how nature and natural functions and processes can be used to build and protect equitable, climate-resilient rural water and sanitation systems.

TABLE S3. Natural Infrastructure Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Removing constraints for natural infrastructure (NI) implementation	Governance, policy, legal, and financial constraints for NI implementation are addressed and removed through context-specific practices to support equitable climate resilience in rural communities.
Centering communities in NI planning	Rural communities and equity are centered in NI planning for climate resilience.
NI projects proactively remove displacement risks	Displacement risks of rural NI projects are identified and addressed at the outset.
NI benefits valued for achieving equitable climate resilience	Context-specific approaches to the valuation of NI for equitable, climate-resilient rural water and sanitation are used in decision making.

Strategies for removing constraints for NI implementation 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 build NI project support and consensus.
4. Use innovative and diverse funding sources appropriate to the local context.

Strategies for centering communities in NI planning include:

1. Incorporate definitions and principles of equity and justice in NI projects.
2. Use community-led decision making for NI planning and implementation.
3. Incorporate transparency, trust building, and mutual learning in community engagement.
4. Form partnerships with trusted individuals or organizations.

Strategies for NI projects proactively removing displacement risks include:

1. Utilize and adapt existing toolkits to identify local risk factors for displacement.
2. Implement locally appropriate and feasible anti-gentrification and displacement policies and practices prior to project construction.



Strategies for NI benefits to be valued for achieving equitable climate resilience include:

1. Utilize comprehensive economic valuation methodologies that center climate resilience, human and ecological well-being, and benefits for multiple sectors and stakeholders.
2. Use complementary tools to understand and communicate the benefits and tradeoffs of NI projects for rural communities.
3. Incorporate nonmonetary valuations that center equity.

Natural infrastructure can be designed to support equitable and climate resilient water and sanitation systems in rural communities. While not every strategy outlined in this section will be appropriate for all rural communities, they can be used as a guide to generate ideas for context-appropriate and locally tailored NI. Governance, policy, legal, and financial constraints to NI implementation can be removed to create more supportive conditions for NI projects. Communities and equity can be centered in each stage of NI planning and implementation to help ensure the needs and priorities of rural community members are meaningfully addressed. Potential displacement risks from NI projects can be identified and avoided prior to implementation. This will allow rural community members to remain in their homes and benefit from the enhanced climate resilience provided by NI. Finally, the potential benefits and tradeoffs of NI projects can be assessed through economic valuation, nonmonetary valuation, or other context-appropriate approaches, to understand how projects will impact equity and climate resilience and to guide decision making.

MANAGEMENT AND PLANNING

This category describes how equity is centered in the way source water protections, community input, financial sustainability, climate impacts and risks, cross-sector coordination, and monitoring and evaluation are incorporated into rural planning and management of water and sanitation.

TABLE S4. Management and Planning Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Source water protections incorporated into water, sanitation, and climate plans and programs	Source water protections are part of water and sanitation planning and management to increase rural community resilience to climate change.
Rural communities centered in climate, water, and sanitation planning and management	Equitable involvement and empowerment of community members in planning and management are achieved by centering rural community priorities.
Rural water and sanitation providers financially sound in the face of climate change	The financial health of rural utilities and communities is supported by proactive, long-term planning and management strategies that result in accessible, affordable, and climate-resilient water and sanitation.
Rural 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 rural 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 in rural communities.
Equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness	Water planners and managers continually monitor and evaluate plans and programs to support equitable and climate-resilient outcomes for rural communities.

Strategies for incorporating source water protections into water, sanitation, and climate plans and programs include:

1. Develop locally tailored source water protection plans by leveraging existing support programs that connect community members and local organizations in collaborative, proactive efforts to safeguard water quality.
2. Include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security.
3. Collaborate with rural communities, scientists, and managers to co-produce tools, plans, and programs that safeguard source water.
4. Integrate education, awareness, and support for private well water quality testing into management frameworks.

Strategies to center rural communities in climate, water, and sanitation planning and management include:

1. Begin with a visioning stage to incorporate rural community insights into climate-resilient water and sanitation planning from the outset.
2. Utilize resources and support from community-based organizations to improve the representation of rural communities in climate adaptation and water and sanitation planning.
3. Foster collaborative research partnerships that provide a boundary function, connecting rural communities with regional and national planning efforts while developing locally tailored resources for self-reliance.
4. Take proactive measures to encourage participation, such as stipends, to empower rural community members to meaningfully engage in management and planning processes.

Strategies to help ensure rural water and sanitation providers are financially sound in the face of climate change include:

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.
3. Employ proactive rate setting to prevent reactive rate increases that could render water and sanitation services unaffordable for rural communities.

Strategies for preparing rural water and sanitation systems for climate disasters and inequitable impacts include:

1. Create emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for rural communities.
2. Develop and utilize local tools on climate disruptions to rural water and sanitation systems to inform residents, encourage participation in planning, and bolster community preparedness.
3. Include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected.
4. Participate in training and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions.
5. Incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for rural communities.

Strategies for cross-sectoral coordination to achieve equitable, climate-resilient water and sanitation include:

1. Align management and planning processes strategically, using integrated and collaborative frameworks.

2. Include interagency and cross-sector working groups in climate disaster response programs and plans to clarify roles, establish coordinated technical assistance programs for rural communities, and incorporate equitable community input into plans.
3. Integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together.
4. Participate in specialized training and exercises to learn how to address climate impacts on rural communities equitably and collaboratively across sectors.

Strategies for equitable, climate-resilient planning and management continually monitored and evaluated for effectiveness include:

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. Use equity-focused indicators to track climate resilience outcomes of water and sanitation plans and programs effectively across rural communities.
3. Allocate specific funding for monitoring and evaluation in climate adaptation planning efforts so that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives.
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 rural communities. Protecting the source water for rural water systems is critical. These communities face challenges to access drinking water and sanitation that are now exacerbated by climate change. Actively engaging rural communities helps to ensure that their needs, cultures, and priorities are centered in planning processes and management efforts. Rural 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 essential. Incorporating community input helps to identify vulnerabilities and design adaptive strategies tailored to rural community needs. Cross-sector coordination can help bridge silos and foster collaboration among stakeholders. This enhances the effectiveness and climate-resilient outcomes of rural water and sanitation plans and management 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 rural communities.

FUNDING AND FINANCING

The funding and financing category describes adequate, sustainable, and equitable funding, financing, and disaster insurance for rural communities to build, adapt, maintain, and restore climate-resilient water and sanitation.

TABLE S5. Funding and Financing Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Funding and financing for capital investments in climate-resilient rural water and sanitation infrastructure	Climate-resilient infrastructure projects for water and sanitation systems serving rural communities and households can obtain and sustain funding and/or financing.
Funding and assistance for climate-resilient operations and maintenance (O&M)	Climate-resilient O&M for water and sanitation systems in rural communities has adequate and sustainable funding and assistance.
Funding, financing, and disaster insurance for climate disruptions	Rural 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	Alternative approaches such as nature-based solutions (NBS), green infrastructure (GI), water efficiency, and water reuse have sustainable, adequate funding sources to support climate-resilient water and sanitation in rural communities.
Affordable climate-resilient water and sanitation for rural households	Rural 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.

Strategies for funding and financing for climate-resilient rural water and sanitation infrastructure include:

1. 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 rural water and sanitation infrastructure.
2. Ensure that funding and financing are accessible and do not have barriers for rural communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure.
3. Enact policies so that rural communities are receiving an equitable amount of benefits from climate and infrastructure funding.
4. Implement technical assistance programs to address barriers experienced by rural communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure.

5. Offer programs to help construct climate-resilient, onsite water and sanitation infrastructure and/or to connect rural homes and communities with decentralized infrastructure to more climate-robust centralized systems.

Strategies for funding and assistance for climate-resilient O&M include:

1. Create and fund grant programs that explicitly name climate resilience and O&M as funding priorities for water and sanitation systems.
2. Work with free technical assistance (TA) providers with climate knowledge and expertise to reduce the financial burden of O&M.
3. Offer programs that provide grants or assistance for income-qualified households to test well water, repair wells or septic systems, or train onsite system owners on O&M.
4. Provide free training and other resources that inform owners on well and septic system operations and maintenance to enhance climate resilience.

Strategies for funding, financing, and disaster insurance for disruptions include:

1. Increase funding available through federal community preparedness and climate hazard mitigation programs for protect-in-place, managed retreat, and relocation, and consolidate funding to improve access to these programs for rural communities.
2. Dedicate funds for declared emergencies in rural areas and simplify and expedite the approval process so funds are delivered quickly.
3. Prevent climate disaster response and recovery efforts from exacerbating or increasing 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.
5. Designate funds for rural households to repair damage caused by disasters, including for repairs to wells and septic systems.
6. Expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities.

Strategies for funding and financing for alternative approaches to equitable, climate-resilient water and sanitation 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 rural communities to identify, apply for, and use the assistance.
3. Enact policies so that rural communities are receiving an equitable amount of benefits of funding for alternative approaches.
4. Offer programs to incentivize or pay for measures that enhance climate resilience of onsite water and sanitation in households in rural communities.

Strategies for affordable climate-resilient water and sanitation for rural households include:

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 so that 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.
4. Create and fund programs to help rural households find leaks and replace inefficient fixtures and appliances to help save on their water, wastewater, and energy bills and support climate resilience.

One of the main barriers to creating equitable, climate-resilient rural water and sanitation systems is inadequate and inaccessible funding. Rural water and sanitation systems need more financial support (e.g., grants and loans) that help them to build and adapt existing infrastructure, improve their ability to operate and maintain their systems, and rebuild and restore after climate emergencies. Rural communities that are dependent on onsite systems, such as wells and septic, also need funding and financing to help them afford costly upgrades and repairs to help protect them from droughts, floods, sea level rise, wildfires, and other climate disasters. This funding is needed to help reduce the cost burden of climate adaptation on rural communities and households, so that they can continue to afford to have running water and adequate sanitation in their homes.



KNOWLEDGE AND INFORMATION

This category describes equitable, transparent, accessible integration and application of technical and community knowledges,³ data, and information to achieve equitable, climate-resilient rural water and sanitation systems.

TABLE S6. Knowledge and Information Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Usable water and climate data at appropriate scales for rural communities	Water, climate, and other relevant data are at the appropriate temporal and spatial scales and readily accessible to decision makers, water managers, and rural communities.
Inclusivity in the use of climate data, projections, and assessments	Climate data and projections are used with the inclusion of rural 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 rural communities and is shared openly and in culturally appropriate formats and languages that are accessible to rural communities.

Strategies for usable water and climate data at appropriate scales for rural communities include:

1. Focus water and climate research and information on community needs and values instead of those of outsiders.
2. Make sure 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.
5. Increase access to trusted support and expertise to increase capacity and overcome technical, legal, and policy barriers.

³ 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.

Strategies for inclusivity in the use of climate data, projections, and assessments include:

1. Use an end-to-end co-production approach in assessing climate risks to include rural 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.
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.

Strategies for incorporation of local and technical knowledges and ways of knowing include:

1. Ensure that local experts and knowledge holders 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.
3. Use appropriate protocols and agreements to protect local knowledge and rural communities.

Strategies for equitable data and information translation, communication, and dissemination include:

1. Present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals.
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.
3. Embrace uncertainty by focusing on what is known and highlighting scientific consensus, while remaining open to new and improved information.
4. Utilize storytelling to effectively convey data, acknowledging and respecting the emotions and psychology of the target audience while validating their experiences.
5. Use credible sources when incorporating climate change into rural water and sanitation initiatives to provide clarity and slow the spread of misinformation.

By valuing and incorporating diverse worldviews 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 rural communities but also foster a deeper understanding and respect for the interconnectedness between humans and their environment. Integration of local, place-based knowledges with technical data and information is essential for achieving equitable, climate-resilient water and sanitation systems in the rural 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, as well as equitable data and information translation, communication, and dissemination can help build capacity for rural communities to achieve equitable, climate-resilient water and sanitation.

CAPACITY BUILDING

This category describes ways to build the capacity of rural water and sanitation professionals, communities, and households with the training, skills, and support they need to equitably adapt to climate change.

TABLE S7. Capacity Building Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Climate-literate and robust water and sanitation workforce representative of their community	The water and sanitation workforce in rural communities is climate-literate, robust, and representative of the communities being served.
Rural community empowerment in water, climate, and sanitation decision making	Rural communities are supported and have sufficient 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 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.

Strategies to support climate-literate and robust water and sanitation workforce representative of their community include:

1. Take advantage of climate adaptation training, programs, and tools 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 groups.
3. Educate students and other career-ready individuals about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.

Strategies for rural community empowerment in water, climate, and sanitation decision making include:

1. Build trust between rural communities and water and wastewater utilities serving them by promoting transparency, inclusivity, and community engagement.
2. Co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with rural communities using community-based participatory research and an asset-based approach.
3. Develop partnerships between rural community members, community-based organizations, and other NGOs to advance community-driven water and sanitation policies.

Strategies to enhance capacity to work with interdependent sectors for climate resilience include:

1. Leverage existing tools and resources, such as the 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.
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.

Strategies to support technical, managerial, and financial (TMF) and leadership skills for equitable climate resilience include:

1. Require TMF trainings for water system board members.
2. Establish formal and informal social networks among underserved systems to share information and resources to help overcome capacity challenges and prepare for climate impacts.
3. Consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity.
4. Take advantage of leadership and TMF training and assistance programs to build capacity to advance climate-resilient strategies.

Capacity building strategies can be implemented to help advance equitable and climate-resilient water and sanitation systems in rural communities. For example, when the water and sanitation workforce in rural communities is representative of the community being served, climate-literate, and robust, the workforce will have better capacity to represent community needs and enhance climate resilience. Culturally appropriate, equitable, and inclusive participation mechanisms can bolster the capacity of rural community members to participate in water, sanitation, and climate decision making. When water and sanitation managers have the capacity to coordinate with interdependent sectors, such as energy and transportation, they increase their ability to prepare for climate impacts and enhance resilience. Finally, empowering water managers with TMF skills can increase their capacity to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.



LAW AND POLICY

The law and policy category describes laws and policies that enable more equitable, climate-resilient construction, operation, and management of rural water and sanitation systems.

TABLE S8. Law and Policy Attributes

ATTRIBUTES	ATTRIBUTE DEFINITION
Laws set structural standards for reliability of services	Federal, Tribal, state, and local governments adopt siting, design, and construction requirements and standards for rural water and wastewater services and infrastructure that explicitly address the impacts of climate change.
Laws protect rights, allocations, and uses of water for domestic purposes	Water rights, laws, and policies are adaptive and flexible so that during times of scarcity, sufficient, safe, physically accessible, acceptable, and affordable water is available for domestic use in rural communities.
Laws require water and wastewater utilities as well as state and local governments to conduct climate resilience planning	The law requires rural water and wastewater systems and government agencies to adopt climate resilience plans to guide water resource management and asset management.
Laws require the creation, collection, and publication of data and information	Laws across all jurisdictions create requirements to monitor and collect data and information critical to preparing rural water and sanitation services and infrastructure for climate change.
Laws appropriate and equitably distribute funding for water and wastewater services and infrastructure	Federal, state, and local laws equitably appropriate and distribute financial resources to fund and finance the rehabilitation of existing and construction of new climate-resilient rural water and wastewater infrastructure.
Laws are enforceable and enforced	Federal, state, and local laws create enforcement mechanisms for drinking water and sanitation systems serving rural communities to meet legal and regulatory standards and include consequences commensurate with noncompliance to reduce risk of harm from climate change impacts to water resources and systems.

For laws to help build more equitable, climate-resilient water and wastewater services and infrastructure in rural communities, they need to set structural standards to ensure reliability of services; protect rights, allocation, and uses of water for domestic purposes; require utilities, states, and local governments to conduct climate resilience planning; require the creation, collection, and publication of information; and appropriate and equitably distribute funding. Furthermore, these laws must be enforceable and enforced.

The law currently takes a largely hands-off approach with decentralized water and sanitation infrastructure, in part because this infrastructure is located on private property. However, this approach minimizes oversight to the detriment of consistency and reliability in providing safe, reliable services over its lifetime, even as the climate changes.

CONCLUSION

We hope that the information herein remains relevant in the future to provide ongoing support to rural communities. Though we recognize some of the strategies may be time-bound or dependent on available opportunities that could change after this report is published.⁴ Notably, many federal resources and funding opportunities related to climate resilience and equity were no longer available under the new White House administration starting in late January 2025. For those programs that have already disappeared from federal sites, we have included archived versions where possible. We also made note of resources and funding programs and mechanisms that are subject to change in the future.

Case examples are included throughout the report to demonstrate the strategies in action in rural communities across the country. Not all case studies presented demonstrate complete feasibility or success. Rather, they are based on available documentation and some perspectives and experiences may not be captured. In addition to sharing case examples for each attribute, we also include resources, such as reports, online toolkits, trainings, and more, to further support rural communities. These resources provide a starting point, though they are only a subset of the many available resources available.

The strategies and approaches identified in this report are for a range of audiences. These include rural communities, their supporters, such as community-based organizations or nonprofits, water resource managers, water and wastewater utilities, policy and law makers, and Tribal, federal, state, and local governments. We recognize the diversity across rural America and, as such, the strategies presented serve as examples of what can be achieved or implemented, not one-size-fits-all solutions. We hope that the information, examples, and resources included in this report can support advancement toward the goal of strengthening the climate resilience of rural water and sanitation in many different locations. Although this will require careful consideration of how to adapt strategies and approaches from one community to another.

More work is needed to better understand and support the needs of and opportunities for rural communities to build and maintain climate-resilient water and sanitation systems. For a full list of gaps and future research directions, see the [Conclusion Section 12](#). Until those needs and opportunities are at the center of efforts to adapt and transform water and sanitation in the face of climate change, any potential solutions will fall short of achieving the goal of equitable, climate-resilient water and sanitation. We present this report as a foundation upon which to build practical solutions for the rural communities who need them the most.

⁴ The report reflects programs and funding available as of April 2025.



1. Preface

As climate change intensifies and accelerates, rural communities will experience many of its impacts through water. Rural communities face distinct challenges in ensuring reliable access to water and sanitation. This report focuses on strategies for rural communities in the United States to strengthen the resilience of their water and sanitation systems to climate change.

This report builds upon existing initiatives, including the [Water and Climate Equity in Rural Communities in the United States](#) project.

- This project is a partnership between the Pacific Institute, Livelihoods Knowledge Exchange Network (LiKEN), and rural communities and technical assistance providers.
- Among the contributions of this project is the report [Water and Climate Equity in Rural Water Systems in the United States](#), an assessment of the climate risks and resilience of rural water systems across the contiguous US with a focus on the Central Appalachia and Southwest regions (Taylor et al. 2024).

This report also builds on [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025), which is the third report in the [Water, Sanitation, and Climate Change in the United States](#) series.

- The third report provided over 100 actionable strategies for strengthening water and sanitation systems in frontline communities, addressing both climate impacts and systemic inequities.
- The first report in the series, [Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States](#), examined how six climate phenomena — extreme temperatures, drought, inland flooding, sea level rise, extreme storms, and wildfires — are disproportionately affecting frontline water resources and water and sanitation systems (Pacific Institute and DigDeep 2024).
- The second report, [Law and Policies that Address Equitable, Climate-Resilient Water and Sanitation](#), was focused on examining how the laws and policies that govern and inform water and sanitation service provision and infrastructure address the impacts of climate change in the US (Campbell-Ferrari et al. 2024).

We hope that the information herein remains relevant in the future to provide ongoing support to rural communities. Though we recognize some of the strategies may be time-bound or dependent on available opportunities that could change after this report is published.⁵ Notably, many federal resources and funding opportunities related to climate resilience and equity are not available under the new White House administration in 2025. For those programs that have disappeared from federal sites, we have included archived versions where possible. We also made note of resources and funding programs and mechanisms that are subject to change in the future.

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 rural US.



⁵ The report reflects programs and funding available as of April 2025.



2. Introduction

Access to safe, affordable, and reliable water and sanitation services is a persistent challenge for many rural communities across the United States. More than two million people in the US live in the water access gap without running water and basic plumbing in their homes. Millions more are served by water systems with Safe Drinking Water Act (SDWA) violations (Roller et al. 2019). Rurality is a significant predictor of inadequate indoor plumbing, alongside factors such as income, poverty, high Indigenous population, lower levels of education, and older populations (Mueller and Gasteyer 2021). As a result, existing water access gaps are clustered in rural areas of the US, such as the Navajo Nation, Appalachia, colonias along the US-Mexico border, and parts of the Deep South (Deitz and Meehan 2019; Roller et al. 2019). In the Navajo Nation, for instance, nearly 30% of households lack running water and must rely on hauled water for daily needs (Navajo Nation Department of Water Resources 2003). Similarly, Appalachia experiences some of the highest rates of households without complete plumbing and/or served by water systems with SDWA violations (Mueller and Gasteyer 2021).

Ensuring the human right to water and sanitation is fundamental to climate preparedness and requires meeting five essential criteria: sufficiency, safety, acceptability, physical accessibility, and affordability (California Environmental Protection Agency 2021; United Nations 2014; Campbell-Ferrari et al. 2024). Climate change is making it increasingly difficult to fulfill universal water and sanitation access in rural areas (Taylor et al. 2024). Rising temperatures, intensified droughts, catastrophic floods and wildfires, and sea level rise threaten the availability and reliability of rural drinking water and sanitation (Pacific Institute and DigDeep 2024; Taylor et al. 2024).

Climate change is already having devastating impacts on rural communities and these impacts are expected to worsen as global temperatures continue to rise (Taylor et al. 2024; World Meteorological Organization 2025). For example, catastrophic flooding across the US is expected to worsen, increasingly disrupting water and sanitation access, with rural communities facing the greatest risk (Anderson and McNeeley 2025). These challenges not only complicate efforts to expand water and sanitation access in rural areas, they also risk backsliding — where communities that previously had access lose it due to climate-related disruptions (Pacific Institute and DigDeep 2024; Roller et al. 2019).

Defining “rural” herein is important, yet there are many definitions in use. The Rural Health Information Hub [compared definitions](#) of rural from federal agencies, including the US Census Bureau, the Office of Management and Budget, and the Economic Research Service of the US Department of Agriculture (USDA) (Rural Health Information Hub, n.d.-b). As seen in Figure 1, the

definition of rural in the US is often based on administrative boundaries, economic influence, and land-use patterns (Cromartie and Bucholtz 2008). As of 2020, the US Census Bureau estimated that 20% of the US population lives in rural areas (US Census Bureau 2022b), but this estimate can vary depending on how rural is defined (Cromartie and Bucholtz 2008). There is significant diversity in rural communities in the US in terms of remoteness, income levels, and demographics (Johnson and Lichter 2022; Rural Health Information Hub, n.d.-b). As such, determining a single definition of rural was not feasible for this report.

FIGURE 1. Comparison of Federal Rural Definitions by Rural Health Information Hub

Comparison of Rural Definitions		
Definition & Agency	Geographic Unit Used	What is Included in "Rural"
Urban and Rural Areas U.S. Census Bureau	Census Blocks and Block Groups	Rural areas encompass all population, housing, and territory not included within an urban area.
Core Based Statistical Areas (Metropolitan, Micropolitan, Noncore) U.S. Office of Management & Budget Metropolitan areas contain a core urban area population of 50,000 or more. Nonmetropolitan areas contain a population of less than 50,000. This includes both micropolitan areas, with urban area populations of 10,000 to 50,000, and all counties that lack an urban core, which are referred to as noncore counties.	County	All nonmetropolitan areas (counties) including micropolitan and noncore counties
Rural-Urban Commuting Areas (RUCAs) Economic Research Service Utilizes the 2010 U.S. Census Bureau's UAs and UCs definitions with information on work commuting. Classification delineates metropolitan, micropolitan, small town, and rural commuting areas with whole numbers 1-10 and further subdivides into 21 secondary codes based on commuting flows — local or to another census tract.	Census Tract, ZIP Code approximation	Primary RUCA codes 4 and above (Micropolitan Area Core, population up to 49,999)
Sources: 2020 Census Urban Areas Facts , U.S. Census Bureau; Rural Urban Commuting Area Codes , USDA-ERS; Urban Influence Codes, Documentation , USDA-ERS		

Source: Rural Health Information Hub, n.d.

Instead, this report takes an inclusive and broad approach in compiling strategies and approaches for climate-resilient rural water and sanitation informed by existing federal and non-federal definitions. Here, rural water and sanitation systems refer to systems that often serve communities in low-population, geographically dispersed areas. These systems are typically classified as “small” by federal standards, generally serving 10,000 or fewer people (US EPA 2015h; 2015a).⁶ While not all small systems are rural, many rural systems fall into this category due to the size and structure of the communities they serve. For example, the National Rural Water Association describes their support for water and wastewater systems as those generally serving communities of 10,000 or fewer people (National Rural Water Association, n.d.-a).

6 Under the Safe Drinking Water Act (SWDA), small public water systems are generally defined as systems serving 10,000 or fewer customers. This category accounts for 92% of the 51,000 community water systems in the United States, and nearly all of the 100,000 noncommunity water systems (US EPA 2015h).

Small and rural drinking water and wastewater systems often face a range of challenges to supply safe and reliable services. Some of these challenges include:

- lack of financial resources;
- aging infrastructure;
- limited technical and managerial capacity;
- lack of long-term planning;
- overbuilt or underbuilt systems;
- insufficient rates that are already too high for customers;
- geographically dispersed populations; and
- difficulty attracting, training, and retaining system operators (Rural Community Assistance Partnership 2020; US EPA 2011; US EPA 2015a).

These challenges can make it difficult for small and rural systems to meet federal requirements (National Conference of State Legislatures 2022). Additionally, these challenges further complicate efforts to respond to and recover from increasing climate-related impacts (Taylor et al. 2024; Pacific Institute and DigDeep 2024). Taylor and co-authors highlighted that climate impacts to rural water and sanitation include, but are not limited to:

- Reduced snowpack, declining water availability, groundwater depletion, increased contaminant concentrations in water, and heightened wildfire risk due to drought;
- Diminished water supplies and deteriorating water quality caused by extreme temperatures;
- Power outages, erosion, landslides, pollutant mobilization, and contamination of community drinking water systems resulting from extreme flooding; and
- Erosion, landslides, sediment buildup, and water resource contamination following wildfires.

These climate change impacts disproportionately affect rural and marginalized communities. For example, Latinos across the US, including in rural regions like colonias along the US-Mexico border, face higher risks of flooding than non-Latino communities (Hernandez 2023).



Some strategies in this report are specific to decentralized water and wastewater systems.⁷ Nearly one in four households in the US depend on individual septic systems or small community cluster wastewater systems (US EPA 2015a). And approximately 15% of the US population relies on private wells as their primary source of drinking water, with most rural residents depending on these wells as their sole supply (US Geological Survey and Water Resources Mission Area 2019).

Decentralized systems encounter additional challenges in maintaining reliable and safe water and sanitation services. For example, decentralized drinking water systems are not regulated by federal drinking water standards, and information and funding assistance for well stewardship is limited (Malecki et al. 2017; Mulhern et al. 2022; Sohns 2023). Onsite wastewater system installation and maintenance can be unaffordable for households, and failure of septic systems is, in part, due to a lack of a centralized regulatory authority (Calabretta, Cunningham, and Vedachalam 2022). Compounding these challenges is climate change. For example, flood waters that pick up pollution from agriculture, industrial sites, and urban surfaces can contaminate groundwater supplies. This can leave private well owners at risk of exposure to chemicals, pathogens, and bacteria in their drinking water (Pacific Institute and DigDeep 2024). Flooding can also overwhelm septic systems by oversaturating the soil — preventing proper drainage and causing wastewater to backflow into homes or yards (Calabretta, Cunningham, and Vedachalam 2022).

Many rural water and wastewater systems face compounding challenges rooted in patterns of political marginalization and uneven infrastructure investments (Edin, Shaefer, and Nelson 2023; Taylor et al. 2024). These can increase the sensitivity of these systems to the climate impacts described above, like catastrophic flooding (Anderson and McNeeley 2025). Taylor and co-authors demonstrated how some areas of Central Appalachia — where coal extraction has left local communities impoverished and underinvested — face limited access to safe drinking water, poor quality, and inadequate wastewater services (Taylor et al. 2024). Development pathways such as these can result in some rural communities across the US facing disproportionate rates of poverty (USDA 2025b) as well as disproportionate impacts from climate change, because multiple risks and economic stressors compound and make it harder for them to prepare or respond (Ribot 2010; Cutter, Ash, and Emrich 2016).

We used a framework developed by Taylor and co-authors to better understand and address the complex and compounding challenges facing rural water and sanitation systems in the US (see Figure 2) (Taylor et al. 2024).

Many rural water and wastewater systems face compounding challenges rooted in patterns of political marginalization and uneven infrastructure investments.

⁷ Decentralized water systems are those that are not connected to interconnected, centralized systems that rely on water treatment facilities and pumping stations or wastewater treatment plants. Here, decentralized systems primarily refer to private wells and onsite septic systems (Pacific Institute and DigDeep 2024).

FIGURE 2. Water and Climate Resilience Framework

Source: Taylor et al. 2024

The framework focuses on rural communities' assets, highlighting their strengths and resources rather than just their vulnerabilities. This shift from a deficit mindset to one of empowerment enables rural communities to take collective action and address climate impacts more effectively. Research has shown that community capital plays a significant role in building resilience in rural areas (Cutter, Ash, and Emrich 2016). Cutter and co-authors included in community capital the following variables: social capital, place attachment, political engagement, and citizen disaster preparedness and response skills. This research points to the importance of focusing on the strengths and resources already present in rural communities when addressing climate and water vulnerability or resilience, using community-centered, asset-based approaches.

Using this framework as guidance, and taking into consideration the unique challenges and assets found in rural communities, this report seeks to answer three questions:

1. What is equitable, climate-resilient rural water and sanitation?
2. What are the characteristics or attributes of equitable, climate-resilient water and sanitation in rural communities?
3. What are the strategies and approaches rural communities are taking to achieve this?

Rural communities and their supporters are making significant progress toward improving water access and climate resilience. This report aims to identify documented strategies and approaches that address both systemic inequities and increasing climate impacts on rural water and sanitation systems. We focus on collaborative, community-centered strategies whenever possible. By valuing the knowledges,⁸ perspectives, and capabilities of those directly affected, these approaches affirm and build on existing assets to empower rural communities in facing climate challenges (Taylor et al. 2024).

While the strategies and case examples of equitable and climate-resilient rural water and sanitation presented in this report offer valuable insights on sustainable and just pathways, we recognize that they may not apply universally to all rural communities given the diverse ways in which “rural” is understood and experienced by different individuals and in different regions.

The rest of the report is structured as follows:

- Section 3 presents the organizing framework from the report [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#).
- Sections 4 through 11 are organized around each of the 8 categories. Within each category there are multiple attributes, and within each attribute there are multiple strategies explored. Available resources and case examples throughout these sections help make the strategies tangible.⁹
- Section 12 is the conclusion and includes a summary of the strategies and approaches we identified, as well as research and knowledge gaps and recommendations for future research.

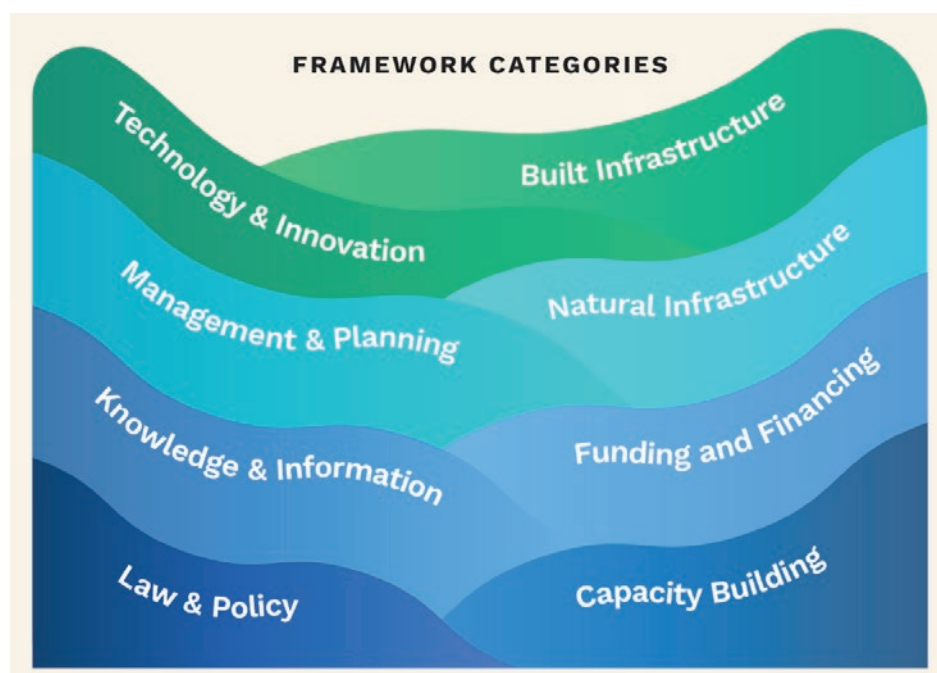
⁸ Although “knowledge” is considered a singular, uncountable noun, we intentionally use the plural “knowledges” to indicate that there is no one monolithic knowledge to understand and address complex issues at the nexus of water and climate equity and that problems and solutions to address climate change require many types of knowledges from myriad disciplines and sources, including local and Indigenous knowledges.

⁹ The Law and Policy category differs from the rest of the report because this is a higher-level review of the laws and policies relevant to the provision of drinking water and sanitation in rural contexts. A forthcoming report on the law and policy strategies will be published in the fall of 2025. Therefore, in this report, this section does not go into detail on the strategies, resources, tools, and rural case examples as are found in the rest of the report.

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

In [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025), we developed a literature-informed framework to categorize and communicate the attributes of equitable, climate-resilient water and sanitation in frontline communities throughout the US. This framework serves as the foundation for this report and is composed of eight categories (Figure 3). These include built infrastructure, natural infrastructure, technology and innovation, management and planning, funding and financing, knowledge and information, capacity building, and law and policy.

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



Note: The figure depicts the eight categories of climate-resilient and equitable water and sanitation that serve as the organizing framework for the attributes and corresponding strategies in this report.

Source: McNeeley et al. 2025

Each category includes multiple attributes of equitable, climate-resilient water and sanitation. To develop the framework and identify the 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 in-person discussions. 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 37 attributes, which we organized into the eight major categories (Figure 3).

For this report, we reassessed the previously identified attributes and strategies and revised them to align with the unique characteristics, challenges, and opportunities in rural communities. Although extensive, this assessment is likely incomplete due to gaps in available data and information. Furthermore, we focus solely on climate impacts and adaptation — we do not address climate change mitigation through reductions in greenhouse gas emissions. More work is needed to refine this framework and fill research gaps, which we identify in [Section 12](#).

3.1. CHARACTERISTICS OF THE STRATEGIES AND APPROACHES TO EQUITABLE, CLIMATE-RESILIENT WATER AND SANITATION IN RURAL COMMUNITIES

We identified and synthesized a diverse set of documented strategies and approaches for rural climate-resilience that were developed for diverse audiences. These audiences include rural communities and their supporters, such as community-based organizations or nonprofits; water resource managers; rural water and wastewater utilities; policy and law makers; and Tribal, federal, state, and local governments.

Rural disaster resilience varies by geography due to differences in social, economic, and infrastructural conditions (Cutter, Ash, and Emrich 2016). As such, the strategies presented here serve as examples of what can be implemented or achieved based on the context in which they have been or were meant to be applied, not as one-size-fits-all solutions for all rural communities. We prioritize strategies that are credible and include context whenever possible to help our readers consider whether and how a similar approach might work in their community. The strategies herein encompass things such as frameworks and activities, policies and programs, or technologies and data to prepare for or respond to harmful climate impacts.

The strategies herein encompass things such as frameworks and activities, policies and programs, or technologies and data to prepare for or respond to harmful climate impacts.

3.2. RESOURCES, TOOLS, AND CASE EXAMPLES

Each section of the report, except [Section 11](#), features a variety of resources (reports, online tools, guides, trainings, and more) that are relevant to rural water and sanitation systems. We discuss real-world case examples that support the outlined strategies. A table at the end of these sections compiles the links and resources to find these materials more easily.

While extensive, these resources represent only a subset of the available materials for strengthening the climate resilience of rural water and sanitation systems. We hope these resources can serve as a starting point for the diverse groups working to support rural water and sanitation systems as they prepare for and respond to a changing climate.

It is also important to recognize that not all case examples presented demonstrate complete feasibility or success. Some have not been fully implemented, monitored, or evaluated, while others lack documented outcomes. This analysis is based on available documentation, acknowledging that other perspectives and experiences may not be captured. However, valuable lessons can still be drawn from these initiatives, and many represent meaningful progress toward rural water and climate resilience efforts.

Most strategies in the report are supported by at least one corresponding resource or case example. However, in some instances, documented examples or tools were not found. These gaps and areas for future research are discussed in the Conclusion [Section 12](#).



4. Built Infrastructure

This category describes new or improved built infrastructure and corresponding strategies aimed at providing equitable, climate-resilient water and sanitation for rural communities.

Built infrastructure that supplies clean, safe drinking water and removes, treats, and discharges treated wastewater to the environment is critical for equitable, climate-resilient water and sanitation. Here, we use built infrastructure to refer to pumps, pipes, storage reservoirs, wells, and treatment plants (i.e., centralized infrastructure). Built infrastructure also includes private wells and septic systems that communities or households construct and maintain for onsite water and sanitation (also called decentralized infrastructure). Rural community populations are small and dispersed, which makes building and maintaining centralized water and sanitation infrastructure infeasible, so they often rely on decentralized infrastructure.

Water and sanitation infrastructure and services have not been equitably provided to all communities and households in the US (Roller et al. 2019). [Water and Climate Equity in Rural Water Systems in the United States](#) described how existing infrastructure already faces a high risk of climate disruptions and damages in rural communities, who have limited resources to adapt or recover from the increasing impacts of climate change (Taylor et al. 2024). These challenges include:

- flooding damage to private wells, onsite septic systems, and centralized water and sanitation systems from hurricanes, heavy precipitation events, and storms;
- melted pipes, wells, water meters, and other equipment during wildfires;
- submerged water and wastewater infrastructure along coastlines from sea level rise;
- extreme heat and drought causing well failures, particularly for shallow wells; and
- extreme cold events leading to ruptured water pipes, power outages, and septic system failure (Calabretta, Cunningham, and Vedachalam 2022; Taylor et al. 2024; Pacific Institute and DigDeep 2024).

This section highlights documented strategies to support rural communities to achieve climate resilience through built infrastructure. We focus on four key attributes:

- 1. equitable access to water and sanitation infrastructure and services;
- 2. climate-resilient infrastructure;
- 3. inclusive and climate-resilient siting, design, and construction; and
- 4. equitable and climate-resilient O&M.

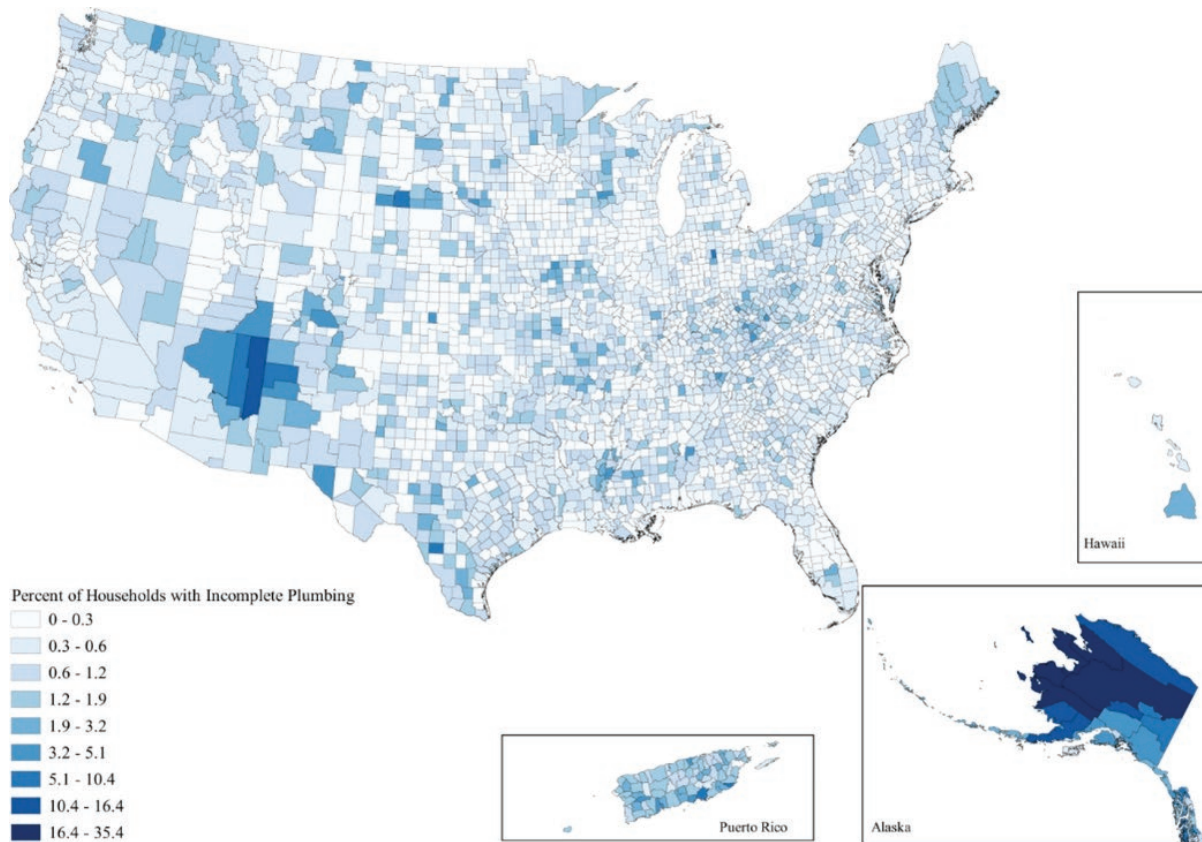
At the end of each attribute section there is a table with a compilation of resources, toolkits, and case examples. This built infrastructure section is interconnected with [Section 8](#) because many of the strategies described below require adequate and accessible funding and financing for rural communities. For additional information and examples of equitable and climate-resilient water and sanitation, see the corresponding Section 4 in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).

4.1. ACCESS TO WATER AND SANITATION INFRASTRUCTURE AND SERVICES

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

To be climate resilient, people and communities need access to safe and affordable water, because many climate change impacts, including droughts, floods, and rising sea levels, directly affect water resources. Yet in the US, frontline communities are often concentrated in “hotspots of plumbing poverty” or regions where there is a lack of complete plumbing, the results from broader social and geographic inequities (Deitz and Meehan 2019). This situation leads to gaps in access to water and sanitation services. These hotspots are found in many rural areas of the US, such as the Navajo Nation, Appalachia, colonias along the US-Mexico border, and the Deep South (Figure 4) (Deitz and Meehan 2019; Mueller and Gasteyer 2021; Roller et al. 2019). Rurality is a key factor identified as a predictor for communities lacking access to complete indoor plumbing, along with income, poverty, Indigeneity, education, and age (Mueller and Gasteyer 2021).

FIGURE 4. Households with Incomplete 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

Many rural communities in the US face heightened risk to climate impacts. This is because of their remote locations, lower populations, economic dependence on local natural resources, high numbers of households without plumbing, reliance on decentralized water and sanitation infrastructure, and/or high rates of poverty (Cutter, Ash, and Emrich 2016; Gowda et al. 2018; Pacific Institute 2023; Taylor et al. 2024). As such, rural communities are subjected to what some have called the “climate gap,” meaning they are disproportionately and inequitably impacted by climate change and extreme climate events (Frosch et al. 2009). This section outlines strategies to ensure rural communities gain access to reliable water and sanitation infrastructure, strengthening their resilience to the impacts of climate change.

One approach is **fostering community-led infrastructure projects through collaborations** with nonprofit organizations and other groups dedicated to closing the water and sanitation access gap. For example, the [Navajo Water Project](#) is a community-centered and collaborative project between DigDeep and multiple other organizations and agencies working on the Navajo Nation, where approximately 30% of homes lack running water (Navajo Nation Department of Water Resources

2003). This Indigenous-led initiative installs onsite water and wastewater systems, repairs and replaces failing septic systems, and offers community-based job training. Additionally, through the Water Is Life Fund, the project provides grants to individuals and communities on the Navajo Nation tackling their own water challenges, like testing water quality (see [Section 8](#) for more details on funding opportunities) (DigDeep, n.d.-b). As of 2024, the project had installed over 750 home water systems, providing running water to more than 2,000 people (McNeeley et al. 2025).

Native American communities are 19 times more likely than White households to lack complete plumbing in their homes (Roller et al. 2019). The Navajo Water Project initiative, and others like it, can support Indigenous communities overcome challenges to water and sanitation infrastructure access. The varying challenges across Indigenous communities include insufficient infrastructure to fully utilize legal water rights, federal funding that lacks input from and is not designed to benefit Tribal communities, and limited Tribal authority to create water districts — all a legacy of settler colonialism (Campbell-Ferrari et al. 2024; Doyle et al. 2018; McNeeley 2017; Status of Tribes and Climate Change Working Group 2021; K. Whyte et al. 2023).

Another example of a community-centered infrastructure project is the [Blackbelt Unincorporated Wastewater Program](#) (BBUWP). The program is a collaboration between counties in Alabama's Black Belt¹⁰ and the BBUWP, a local nonprofit organization. It was initially created to address the urgent need for proper wastewater disposal in Lowndes County, Alabama and has since expanded in scope to other Black Belt counties. This region is known for its limited access to municipal utilities and nonabsorbent clay soil that prevents traditional septic tanks from draining properly (The Blackbelt Unincorporated Wastewater Program, n.d.; International Water, Sanitation and Hygiene Foundation 2022). Because of high poverty levels, low population density, and the rural landscape, access to public wastewater infrastructure is infeasible in the Black Belt (International Water, Sanitation and Hygiene Foundation 2022). With conventional septic systems failing, many residents in the region have no choice but to use the dangerous practice of straight piping in which untreated household wastewater is discharged into nearby ditches or streams. This practice poses significant health risks, including contamination of water bodies with fecal coliform bacteria, which can cause illness in both humans and animals upon contact (US EPA 2002; Walton 2018). To combat this, BBUWP installs innovative onsite wastewater systems that treat and clean wastewater before disposal, sending clean water into the soil. The program also provides educational outreach and monitoring and maintenance for low-income rural

The varying challenges across Indigenous communities include insufficient infrastructure to fully utilize legal water rights, federal funding that lacks input from and is not designed to benefit Tribal communities, and limited Tribal authority to create water districts — all a legacy of settler colonialism.

¹⁰ The Black Belt region of Alabama refers to a set of 17 counties arcing through the South-central part of the state where there is dark, fertile soil and a high number of historically enslaved Africans and African Americans (The Blackbelt Unincorporated Wastewater Program, n.d.; US National Park Service, n.d.). The region is designated as a National Heritage Area.

homeowners. The program is phased, Phase One aiming to serve at least 100 homes, and future expansion dependent on additional funding.

BBUWP and similar programs help rural communities overcome the financial barrier of installing conventional septic systems, which can cost between \$8,000 and \$30,000 (Calabretta, Cunningham, and Vedachalam 2022). The risk of septic system failures grows with extreme precipitation events. Heavy rains are increasing in the Southeastern US, for example, causing more frequent flooding (Calabretta, Cunningham, and Vedachalam 2022). BBUWP strengthens rural households' resilience to climate impacts by ensuring proper wastewater treatment and maintaining reliable access to safe sanitation, even during extreme weather events. Although it is important to note that even properly functioning onsite systems can fail during catastrophic climate events. For example, onsite wastewater treatment systems in coastal areas are increasingly at risk of failure due to sea level rise, rising groundwater tables, and storm surge (Vorhees et al. 2022).

Another strategy that supports rural communities' access to water and sanitation infrastructure is to **create and utilize programs that connect rural households and communities with climate-resilient centralized water and/or sanitation systems**. Some rural communities lack the capacity to apply for water infrastructure and climate change adaption funding (Taylor et al. 2024). Additionally, some rural households cannot afford to maintain and repair decentralized infrastructure (Calabretta, Cunningham, and Vedachalam 2022). For rural communities reliant upon aging or failing decentralized water and sanitation infrastructure, a way to address these challenges is to connect them to centralized systems.

The Environmental Protection Agency's (EPA) [Closing America's Wastewater Access Gap Initiative](#) provides free technical assistance (TA) to rural communities with failing septic systems or without existing wastewater infrastructure across the US. Participants of the program receive support to identify their communities' needs and identify feasible options to improve wastewater infrastructure (US EPA 2022d). For example, Dunlap, an unincorporated community in Mississippi, used the free TA to help formulate a plan for connecting to centralized sewer services from the neighboring city of Mound Bayou. While the initiative is not explicitly climate focused, it can support rural communities in upgrading their sanitation infrastructure or connecting to neighboring centralized systems, both of which can enhance climate resilience.

Table 1 lists the two strategies for rural access to water and sanitation infrastructure shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 1. Strategies, Resources, and Case Examples for Rural Access to Water and Sanitation Infrastructure and Services

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
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 in rural areas. 2. Create programs to connect rural households and communities with water and sanitation systems at risk from climate impacts to more climate-robust centralized water and/or sanitation systems.	• Closing America’s Wastewater Access Gap Initiative (US EPA 2022d) (2) • Rural Utilities Service Water and Environmental Programs (USDA n.d.-e) (2) • RCAP Regionalization resources (Rural Community Assistance Corporation 2021) (2) • Rural Community Development Program (US Department of Health and Human Services 2023) (+)	• DigDeep Navajo Water Project (DigDeep, n.d.-c) (1) • BlackBelt Unincorporated Wastewater Program (The Blackbelt Unincorporated Wastewater Program, n.d.) (1) • Duke University and Alabama Center for Rural Enterprise¹¹ partnership to improve sanitation access in Lowndes County (Duke Bass Connections, n.d.) (1)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

¹¹ Alabama Center for Rural Enterprise (ACRE) is the predecessor of the current [Center for Rural Enterprise and Environmental Justice](#) (CREEJ).

4.2. RELIABLE PERFORMANCE UNDER A RANGE OF CLIMATE CHANGE IMPACTS

Attribute description: Built infrastructure performs reliably under a wide range of climate conditions to deliver safe, sufficient, and acceptable water and sanitation for rural communities.

Climate change is drastically altering the water cycle in ways that will challenge water and sanitation infrastructure to perform reliably in rural communities (Pacific Institute and DigDeep 2024; Taylor et al. 2024). Most of the drinking and wastewater infrastructure in the US was built based on historical climate and assuming stationarity (the notion that the range of climate variability does not change over time) (Milly et al. 2008). However, scientists and water managers increasingly recognize that the past is no longer a reliable predictor of future conditions (Marvel et al. 2023; Payton et al. 2023). To achieve equitable, climate-resilient rural water and sanitation, infrastructure must be designed to withstand a wider range of climate extremes.

The American Society of Civil Engineers' 2025 report card rated US drinking water infrastructure a C-, while wastewater and levees received D+ grades and stormwater received a D (American Society of Civil Engineers 2025). These results point to aging systems, frequent failures, and underinvestment in water and sanitation infrastructure. While the grades do not directly measure climate resilience, they indicate widespread infrastructure vulnerabilities. Many rural communities and systems face heightened risk because of remoteness, historical disinvestment, and low population density, all of which contribute to a lack of capacity and financial resources to build and maintain infrastructure (Taylor et al. 2024).

Notably, little is documented about the reliability or condition of water and sanitation onsite systems that serve single households, like the domestic wells and septic tanks that are more common in rural areas (US EPA 2021c). 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; Taylor et al. 2024). This section includes strategies to improve rural water and sanitation infrastructure resilience to achieve reliable performance under a range of climatic extremes.

Widespread failing infrastructure means that those responsible for operating and maintaining rural water and sanitation systems need ways to **assess infrastructure reliability under a range of climate conditions**. Several tools and frameworks for evaluating the climate resilience of water infrastructure have been developed, including the EPA's [Vulnerability Self-Assessment Tool](#) (VSAT). VSAT was made for both small and large utilities to help identify the highest risks, including climate risks, to their "mission-critical operations" as well as cost-effective measures to reduce those risks (US EPA 2015j). This tool, along with additional resources in Table 2 below, is available to help rural utilities evaluate the climate resilience of existing water and sanitation infrastructure.

To achieve equitable, climate-resilient rural water and sanitation, infrastructure must be designed to withstand a wider range of climate extremes.

Another strategy to enhance the climate resilience of rural infrastructure is **strengthening water reliability through targeted improvements, such as water reuse, water efficiency, recharging aquifers, and deepening groundwater wells.** These activities must be tailored to the water challenges and opportunities in the places where they are being implemented, and they will be most successful if they can perform under a range of climate conditions, shocks, and stresses. For example, the Chickasaw and Choctaw Nations of Oklahoma have led adaptation projects addressing climate impacts on their water supply, primarily the Arbuckle-Simpson Aquifer. These Nations have worked with rural 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 so that infrastructure is functioning efficiently, and water supplies are available to all communities in the region, even during times of drought.



Physical connection to another drinking water system can help prevent disruptions from unexpected or extreme events for small and rural communities (Dobbin, McBride, and Pierce 2023). Physical connections created between two or more water systems are referred to as “consolidation,” named so because the connected systems often end up creating a shared governance structure that makes them a single consolidated water system. 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).¹² There is evidence that consolidating systems can reduce the number of Safe Drinking Water Act violations in small systems, which typically rely on a single source and are among the most vulnerable to climate impacts (Dobbin, McBride, and Pierce 2023; Mullin 2020). However, Dobbin and co-authors found that consolidation typically occurs between systems within one mile of each other, making it a potentially less viable strategy for more remote rural communities. Although many researchers and government agencies promote interconnections to address a wide range of technical, managerial, financial (TMF) and resilience challenges, communities have opposed them because of the perceived or real loss of local control (Dobbin, McBride, and Pierce 2023; Mullin 2020). Also, consolidation does not always equitably serve low-income communities and communities of color (Dobbin, McBride, and Pierce 2023).

¹² Partnerships can range in formality from informal cooperation, to contractual assistance, to shared governance, to a complete ownership transfer (Landes et al. 2020).

Despite some drawbacks, consolidation and partnerships between rural utilities can increase resilience of rural water and sanitation systems. RCAP provided policy recommendations and lessons learned along with useful resources for understanding key governance and equity considerations when pursuing different kinds of interconnection agreements (Landes et al. 2020; 2021). For example, they identified support for system leaders and boards to better understand their roles and responsibilities as a key lesson learned for successful partnerships between different rural community water and/or wastewater systems (Landes et al. 2020). The most effective partnerships RCAP identified were those in which boards or other decision-making bodies included individuals who recognize the importance of water and wastewater infrastructure and are dedicated to ensuring the system's long-term sustainability for their community and region. One of the policy recommendations for local, state, and federal governments includes incentivizing “regionalization efforts through intentional, targeted, and more favorable funding terms” (Landes et al. 2021).

In rural coastal communities, sea level rise poses a threat to both centralized and decentralized rural water and sanitation infrastructure. For example, centralized wastewater infrastructure is commonly located along waterways at lower elevations than the communities they serve. This makes them susceptible to flooding and sea level rise, which are becoming more frequent and intense due to climate change (Pacific Institute and DigDeep 2024).

Elevating infrastructure above flood-prone areas is a strategy to help address this challenge. To assist rural communities with limited capacity to assess elevation strategies, the EPA's [Creating Resilient Water Utilities](#) (CRWU) and [Climate Resilience Evaluation and Awareness Tool](#) (CREAT) offer valuable analysis and planning support. For example, the Beaufort-Jasper Water and Sewer Authority in Okatie, South Carolina used CRWU and CREAT to identify priorities for reducing flood damage to their wastewater infrastructure from sea level rise and storms (US EPA 2023h). Two adaptive measures identified included assessing which wastewater pumping stations may need to be elevated and raising electrical control panels to prevent flood damage.

Flooding caused by rising sea levels and extreme precipitation also threatens rural onsite systems with septic systems and wells (Calabretta, Cunningham, and Vedachalam 2022; Robbins 2025). For

example, higher groundwater levels from sea level rise and inland flooding can impair the effectiveness of septic systems, preventing proper filtration and drainage. This can cause sewage backups into homes and contamination of soil and waterways (Morrison 2022). **Onsite septic systems can be upgraded to more innovative versions that more effectively filter nitrogen and phosphorus to improve their resilience** (Calabretta, Cunningham, and Vedachalam 2022). These advanced systems can better accommodate poor soils and reduce contamination by capturing and reusing waste, yet rising groundwater levels threatens even advanced systems.



Alternatively, **septic systems can be elevated by constructing them in mounded sand to create an artificial buffer to rising water levels** (Graff 2024; Walls, DeAngeli, and Liao 2023). However, these strategies may only temporarily protect septic systems. Sea level rise could eventually threaten the viability of any coastal septic system, regardless of improvements (Walls, DeAngeli, and Liao 2023). Rural coastal communities need updated septic system regulations that consider climate change impacts on infrastructure, such as sea level rise, coastal flooding, and salt water intrusion (Graff 2024; US EPA 2024h).

Wildfires have many adverse effects on rural water infrastructure, including, but not limited to, melted and ruptured meters and pipes, damage to intake systems and water treatment plants, and degraded water quality (Bladon et al. 2014; Pacific Institute and DigDeep 2024; Taylor et al. 2024). Some rural water systems were not built to withstand wildfires, which can leave communities without water and sanitation for an extended time post fire (Becker 2020). An example of this was in 2018 in Butte County, California, when the Camp Fire caused extensive damage to the town and water infrastructure and contaminated the drinking water with dangerous levels of benzene (see Figure 5) (Proctor et al. 2020).¹³ Drinking water contamination during and after wildfires occurs when burning plastic materials release harmful compounds and low water pressure allows smoke and hot gases to enter water lines (US EPA 2021a).

FIGURE 5. Destruction Caused by 2018 Camp Fire in California



Source: Walton 2019; Photo Credit: Brett Walton/Circle of Blue

¹³ Benzene is a volatile organic compound (VOC) that is found in nature and human-made materials like oil, gasoline, and plastics. Long-term exposure of benzene can cause serious health issues, including cancer (Center for Disease Control 2024).

To prepare for wildfire impacts, water system engineers recommend **updating drinking water distribution systems with backflow prevention devices on service lines and meters with the ability to automatically shut-off, as well as keeping plastic infrastructure away from heat sources** (Whelton et al. 2023). Whelton and co-authors emphasized that these changes could help reduce the potential for damage, depressurization, and contamination of a community's infrastructure and water in the event of wildfire. Additionally, county and state agencies are encouraged to offer educational and financial assistance to support rural households to test and inspect wells before and after wildfires (Jankowski et al. 2023) (see more in [Section 7.1](#)).

Lastly, **water and sanitation infrastructure can be relocated to protect them from future climate impacts** when necessary. For example, the remote Alaska Native Yup'ik village of Newtok, located near the coast along the Ningliq River in southwest Alaska, like many rural Alaska villages, has been relocating its critical infrastructure and community structures to higher ground since the 1990s (Alaska Department of Commerce 2024). Newtok has experienced severe climate change effects, including permafrost degradation, sea level rise, flooding, and shoreline erosion rates of 70–90 feet per year (Newtok Village Council 2017). This has resulted in the loss of vital infrastructure, including drinking water and wastewater systems. In response, the village is relocating with support from the state of Alaska to Mertavik, an area 9 miles upriver. In 2023, the village was awarded an EPA Drinking Water System Infrastructure Resilience and Sustainability grant to support the construction and relocation of their drinking water system (US EPA 2023c).

Although the relocation has provided a safer geographic location, residents in Mertarvik still face significant challenges in accessing reliable water and sanitation services (Schwing 2025). This is due to poor-quality infrastructure, inadequate federal oversight, and fragmented coordination supporting across agencies. These issues underscore the lack of a comprehensive national framework for climate relocation and the need for long-term, culturally informed support that does not place disproportionate burdens on underresourced communities (Schwing 2025).



Table 2 lists the six strategies for climate-resilient rural water and sanitation infrastructure shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 2. Strategies, Resources, and Case Examples for Climate-Resilient Rural Water and Sanitation Infrastructure

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Create and utilize tools and frameworks for rural water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure. 2. Improve rural water reliability through water reuse, water efficiency, 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. Update and/or elevate centralized and decentralized water and wastewater infrastructure to protect it from sea level rise and inland flooding. 5. Adapt rural 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. 6. When necessary, relocate rural community water stations and other infrastructure to protect them from damage and destruction.	• Climate Resilience Evaluation and Awareness Tool (US EPA n.d.-a) (+) • Creating Resilient Water Utilities (US EPA 2024b) (+) • Vulnerability Self-Assessment Tool (US EPA 2015j) (1) • “How tough is WASH framework” (Howard et al. 2021) (1) • Water Resilience Assessment Framework (WRAF) (CEO Water Mandate 2024) (1) • Resiliency through Water and Wastewater System Partnerships: 10 Lessons from Community Leaders (Landes et al. 2020) (3) • Regionalization: Rural Community Assistance Partnership’s Recommendations for Water and Wastewater Policy (Landes et al. 2021) (3) • Wildfire Incident Action Checklist for water and wastewater utilities (US EPA 2015c) (5) • Addressing Contamination of Drinking Water Distribution Systems from Volatile Organic Compounds (VOCs) After Wildfires (US EPA 2021a) (5) • Community Planning Assistance for Wildfire (Community Planning Assistance for Wildfire, n.d.) (5)	• Status of Tribes and Climate Change Report Chapter 4.2.1 Chickasaw Nation and Choctaw Nation of Oklahoma Leading the Way in Implementing Adaptation Projects (Status of Tribes and Climate Change Working Group 2021) (2) • Beaufort-Jasper Water and Sewer Authority Wastewater Planning for Resilience (US EPA 2023h) (4) • Investing in climate-resilient wastewater infrastructure on Smith Island, Maryland (Cannon 2024) (4) • Village of Newtok relocation effort (Alaska Department of Commerce 2024) (6)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

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 to center rural community values and needs.

The siting, design, and construction of centralized and decentralized water and wastewater infrastructure require careful consideration of community needs along with multiple other factors. These include technical specifications, regulatory requirements, costs, climate resilience, and both benefits and possible negative impacts on the community. In addition, infrastructure projects require a “social license to operate,” which is to gain acceptance and approval by the local community. Without a social license, a project may become socially and politically infeasible (Jijelava and Vanclay 2018).

Centralized water and sanitation infrastructure often have localized negative impacts on nearby households or communities, while their benefits may be more widely distributed. For instance, wastewater treatment plants are usually placed in specific locations, sometimes near water bodies, where they can impact nearby residents through noise, odors, and changes in water quality. Extreme weather events with heavy rainfall can overwhelm centralized systems and cause overflow events, exposing communities to untreated sewage. Hurricane Sandy in 2012, for example, caused 11 billion gallons of untreated sewage to flow into waterways, impacting both urban and rural communities (Kenward, Yawitz, and Raja 2013). Climate change is expected to increase the frequency and severity of heavy precipitation events (Marvel et al. 2023), leading to more instances of sewer overflow that most directly affect communities surrounding and just downstream of them.

A pertinent strategy for equity and inclusivity in rural water and sanitation infrastructure design, siting, and construction is to **create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience**. Developing and following this type of guidance, the US Water Alliance recommends turning infrastructure into community assets by designing it 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). However, multi-benefit amenities can also contribute to increased housing costs and property values, which can drive gentrification and the displacement of local residents (Checker 2011; Wolch, Byrne, and Newell 2014). The US Water Alliance also emphasized the importance of minimizing construction impacts on local neighborhoods, such as from 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 (Simonson 2022). These tips can help rural communities consider inequitable impacts when designing, siting, and constructing water and sanitation infrastructure.

Likewise, the US Water Alliance’s [Racial Equity Toolkit](#) is a helpful guidance for integrating equity into all aspects of water utility planning (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. The toolkit advises utilities to prioritize infrastructure projects that enhance climate resilience, address community needs, and provide multiple benefits while mitigating future climate impacts (US Water Alliance 2022). While these resources are not specific to the rural context, they are free and can be used by small water and sanitation systems to develop inclusive processes in their infrastructure development efforts.

Including direct input from rural community members into infrastructure design, siting, and construction is another strategy. Community members with lived experience and strong ties to their communities can play a crucial role in collecting data and assessing infrastructure access inequities (Albright et al. 2024). As discussed in [Section 4.1](#), residents in Lowndes County Alabama face social, racial, and environmental inequities such as endemic poverty, hazardous health conditions, and inadequate sanitation infrastructure (Albright et al. 2024). University researchers partnered with a local nonprofit to survey community members in Lowndes County about perspectives on household sanitation infrastructure access. Failing septic systems and raw sewage were identified as severe problems by 59% of county residents surveyed. The researchers argued that the perspectives, needs, and preferences of underserved rural areas are increasingly important for equitable investments in wastewater infrastructure. Household-level insights into sanitation access help identify key barriers and guide the development of effective, climate-resilient infrastructure design and siting.



Another related initiative at the federal level for equitable and inclusive wastewater infrastructure was the EPA’s [Lagoon Wastewater Treatment Plan](#).¹⁴ The plan’s goal was to enhance public health and waterway protections for small, rural, and Tribal communities using lagoon wastewater systems through equitable, accessible, and coordinated technical and financial support (US EPA 2022f). One of the actions was to develop community engagement, communication, and partnerships to support the plan. As part of its broader plan, the EPA analyzed state and Tribal lagoon systems, incorporating socioeconomic data to inform community engagement strategies (US EPA 2022g). While there are no documented outcomes of the community engagement efforts to date, the plan serves as an example of a federal initiative designed to equitably address wastewater challenges through inclusive design of wastewater lagoons. This in turn can increase resilience to climate change in rural communities by ensuring lagoons are prepared for climate events, like heavy rainfall or drought.

Structural and systemic racism and the disenfranchisement of communities of color, Tribes and Indigenous communities, and otherwise marginalized groups have led to the exclusion of important rural stakeholders from water-related decision making (Anguelovski et al. 2016; Braveman et al. 2022; David-Chavez and Gavin 2018; Fernandez-Bou et al. 2021). The exclusion of certain communities from decision making, either intentionally or unintentionally, is a form of procedural injustice. Procedural injustice in water-related decision making often leads to an unfair distribution of the risks and benefits of those decisions, which is a form of distributive injustice (Balazs and Lubell 2014; Solis 2018; 2023). The strategies in this section support procedural and distributive justice by including historically marginalized communities in climate-resilient water and wastewater infrastructure decision making and outcomes.

The strategies in this section support procedural and distributive justice by including historically marginalized communities in climate-resilient water and wastewater infrastructure decision making and outcomes.

Table 3 lists the two strategies for inclusive siting, design, and construction of rural water and sanitation infrastructure shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.



¹⁴ This plan was intended to cover 2022–2026, though its future is uncertain under the federal administration as of 2025.

TABLE 3. Strategies, Resources, and Case Examples for Inclusive Processes for Siting, Designing, and Constructing Rural Water and Sanitation Infrastructure

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience.	• Centering Water Equity in Capital Projects: Applying Equitable Infrastructure Principles Across the Infrastructure Cycle (Simonson 2022)¹⁵ (1) • Racial Equity Toolkit (US Water Alliance 2022) (+) • Lagoon Wastewater Treatment Action Plan: Supporting Small, Rural, and Tribal Communities (US EPA 2022f) (2)	• Failing septic systems in Lowndes County, Alabama: Citizen participation, science, and community knowledge (Albright et al. 2024) (2)
2. Incorporate direct input from rural communities when siting and designing climate-resilient water and sanitation.		

4.4. EQUITABLE, CLIMATE-RESILIENT OPERATIONS AND MAINTENANCE

Attribute description: The operations and maintenance of water and sanitation improve climate resilience and facilitate equitable outcomes for rural communities.

Operations and maintenance (O&M) are essential for water and sanitation systems. O&M refers to ongoing activities required to run and maintain water and sanitation systems, as well as routine checks, repairs, and adjustments of equipment to optimize efficiency and reliability. Climate-resilient O&M includes standard practices as well as additional measures specifically designed to address the impacts of climate change on infrastructure. As described in [Section 4.3](#), insufficient maintenance of water and sanitation infrastructure can pose health risks to rural communities. Small rural communities in the US encounter distinct challenges in wastewater treatment and water quality management, largely due to limited financial resources and staffing for facility O&M (US EPA 2022g). For example small, rural communities and utilities often struggle to afford increasing water treatment costs associated with a changing climate (USDA 2017).

One strategy to support climate-resilient O&M is to **identify specific O&M tasks that must be performed or adapted to protect rural infrastructure from climate impacts**. For instance, changing hydrologic conditions may require dam operators to adjust practices — such as reservoir releases — to balance competing water demands in times of water scarcity (Ehsani et al. 2017). Wildfire-impacted drinking water sources may necessitate new treatment approaches like additional phases of treatment for fine particulates (Chow et al. 2019; Wandersee et al. 2023). Also, drought-induced

15 This resource is no longer available on US Water Alliance’s website. The link provided is an archived version.

reductions in wastewater flows can impact maintenance processes, like the need for additional or different chemicals to treat more concentrated influent (Porse et al. 2023). O&M of decentralized water and sanitation infrastructure will also require new approaches because of the increased risk of failure caused by climate change (Calabretta, Cunningham, and Vedachalam 2022). For example, the use of monitoring technology may help to track the performance of septic systems that are at risk of rising groundwater levels and sea level rise (Vorhees et al. 2022).

Small water systems often face difficulties funding infrastructure O&M because they have fewer ratepayers to share these costs (National Conference of State Legislatures 2022). Tribes and Tribal-owned utilities on Reservations face unique barriers to climate-resilient and equitable O&M of infrastructure. For example, while water districts are a common mechanism used by off Reservation communities to tax and raise funds for operating and maintaining water and wastewater systems, Tribes on Reservations lack the legal authority to create water districts (Doyle et al. 2018). See [Section 8.2](#) for more information on funding rural water infrastructure O&M.

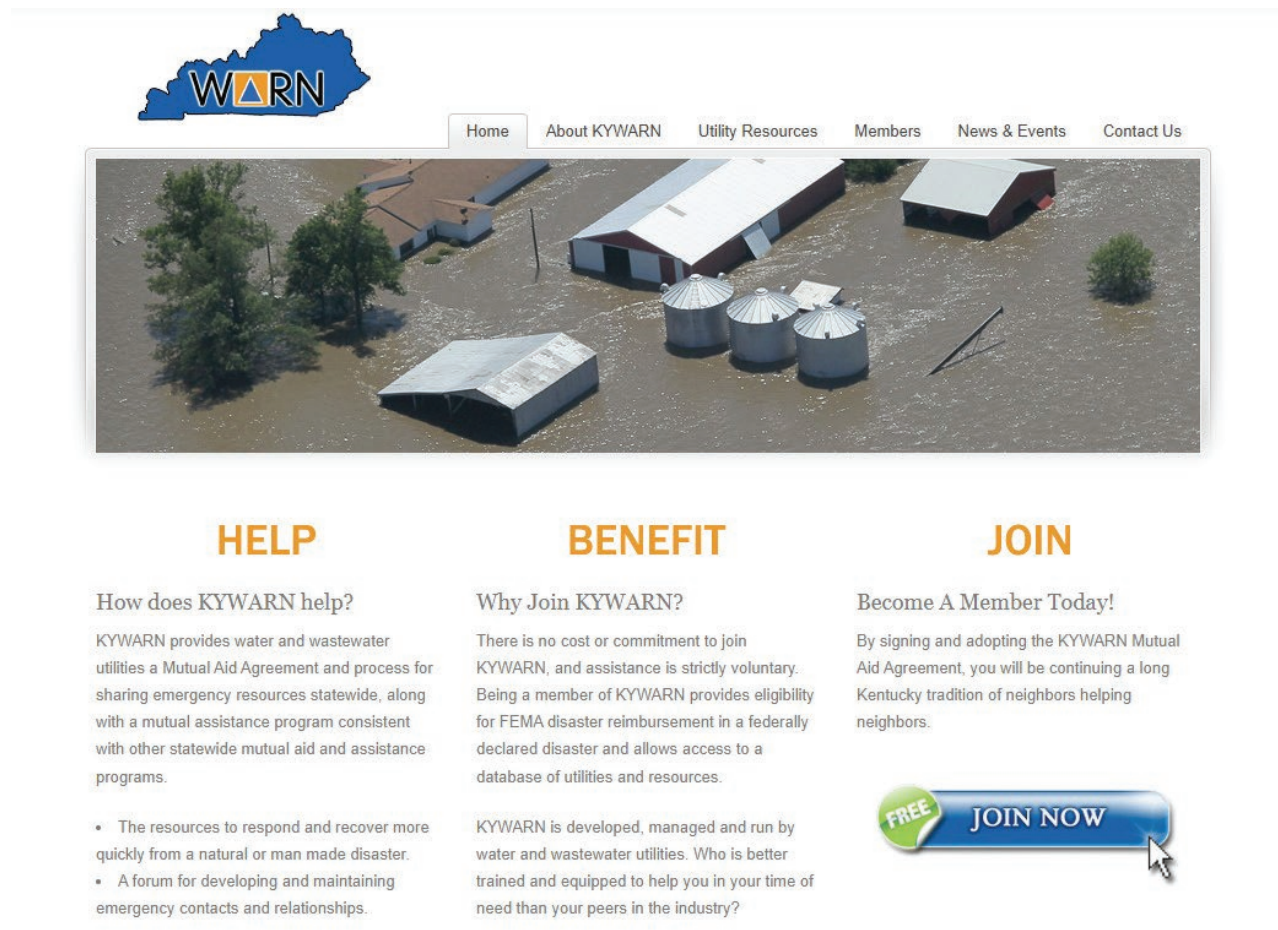
Rural utilities can also **establish emergency response systems to support operators in continuing O&M of water and sanitation infrastructure during climate emergencies.**

To do this, they can leverage support from programs and TA providers. The National Rural Water Association, a nonprofit that serves water and wastewater operators in small, rural communities across the US, operates the USDA's [Circuit Rider Program](#) (National Rural Water Association 2020a). This program provides assistance and training for every aspect of O&M, including TMF support. This covers a variety of O&M functions, from routine tasks like leak detection support to emergency response procedures and protocols. 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, and greater household satisfaction, participation, and rates of water fee payments.

To be better prepared for emergencies, the RCAP TA providers identified the need for lists of water operators in nearby regions to help operate and maintain systems during disasters (Taylor et al. 2024).¹⁶ There are existing programs to connect rural utilities with nearby utilities for O&M support during times of disaster. Water/Wastewater Agency Response Networks (WARNs) are mutual aid networks for water operators in all states (except Mississippi) (US EPA 2023f). Figure 6 provides an example of a webpage from the Kentucky WARN. WARNs enable water and wastewater utilities to quickly access personnel, equipment, materials, and services from other utilities, ensuring a swift restoration of critical operations during emergencies.

Rural utilities can establish emergency response systems to support operators in continuing O&M of water and sanitation infrastructure during climate emergencies.

¹⁶ RCAP technical assistance providers offer training, resources, and support to private well or septic system owners and rural, Tribal, or *colonias* water and wastewater system operators.

FIGURE 6. Kentucky WARN Program Webpage

Source: Kentucky Water/Wastewater Agency Response Network (KYWARN), n.d

Rural water and sanitation utilities can use **online tools and resources to support climate-resilient O&M**. The US EPA’s Office of Water hosts periodic, free, online resilience trainings for water and wastewater utilities (US EPA 2024g). Many of these are offered through the [Creating Resilient Water Utilities](#) (CRWU) program mentioned earlier. The program provides water, wastewater, and stormwater utilities with tools, training and TA to increase infrastructure resilience to climate change by identifying adaptation strategies. This includes O&M strategies and approaches that build climate resilience (US EPA 2024b). The CRWU program hosts the [Climate Resilience Evaluation and Awareness Tool](#) (CREAT), a tool to assist water sector utilities in assessing climate-related risks to assets and operations and for identifying adaptation options. For example, the village of Hershey, Nebraska, identified adaptive measures including securing backup power supply, setting up mutual-aid agreements between local communities, and developing a drought contingency plan to better prepare for and respond to drought (US EPA 2023i). The EPA also provides [resilience checklists for small utilities](#) (serving 50,000 or fewer people), helping staff assess climate hazards — such as floods, wildfires, and storms — and their impact on O&M, chemical storage, finances, monitoring, and infrastructure (US EPA 2020).

Rural water and sanitation operators can engage with community members to **prioritize O&M work that addresses long-standing inequities in service resulting from racism, disinvestment, and marginalization**. As such, incorporating equity into rural O&M may require different skills than those needed for addressing climate resilience. The US Water Alliance recommends that utilities incorporate equity into their O&M by prioritizing infrastructure maintenance, repair, and replacement based on community need and equity-driven criteria (Simonson 2022). Complaints to utilities tend to be disproportionately concentrated in wealthy areas with high levels of service (Simonson 2022). Rather than relying only on complaint-based systems, the recommendation echoes the call repeated throughout this report for direct engagement with rural communities in decision making. 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 address long-standing inequities.

A partnership between the nonprofit WaterNow Alliance and Wake County, North Carolina, demonstrates how rural communities can be centered in O&M of water and sanitation infrastructure. Low-income residents who rely on onsite systems face health risks from septic system failures and well contamination but often cannot afford repairs. To address this, the county and WaterNow Alliance collaborated to design an equitable outreach strategy for a two-year pilot program that offers financial aid for well and septic system repairs and water testing for low-income and elderly residents in both urban and rural areas (WaterNow Alliance, n.d.-c). They engaged community members to build trust, understand barriers, and increase program awareness. A key output of the project was the [Well & Septic Pilot Assistance Fund Community Engagement and Outreach Toolkit](#), a resource to help local agencies or utilities engage their residents in the development and implementation of similar programs.

Table 4 lists the five strategies for climate-resilient O&M of rural water and sanitation infrastructure shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.



TABLE 4. Strategies, Resources, and Case Examples for Equitable and Climate-Resilient Operation and Maintenance for Rural Water and Sanitation Infrastructure

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Identify specific operations and maintenance (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 so that rural 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 O&M tasks needed for improving climate resilience. 5. Engage directly with rural communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.	• Creating Resilient Water Utilities (US EPA 2024b) (+) • Climate Resilience Evaluation and Awareness Tool (US EPA n.d.-a) (+) • Circuit Rider Program (National Rural Water Association 2020a) (2, 3) • Water and Wastewater Agency Response Networks (US EPA 2023f) (2) • Technical Assistance for Rural, Small, and/or Tribal Lagoon Wastewater Treatment Systems (US EPA 2024k) (3) • Training and Technical Assistance Program for Rural, Small, and Tribal Wastewater Systems (US EPA 2023g) (3, 4) • Well & Septic Pilot Assistance Fund Community Engagement and Outreach Toolkit (WaterNow Alliance 2024) (5)	• Wake County and WaterNow Alliance Equitable Outreach Strategy for Well and Septic Financial Assistance Pilot Program (WaterNow Alliance, n.d.-c) (5) • Kentucky WARN (Kentucky Water/Wastewater Agency Response Network (KYWARN), n.d.) (2)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

4.5. BUILT INFRASTRUCTURE SUMMARY

Expanding access to safe, reliable, and climate-resilient water and sanitation infrastructure is essential for ensuring rural communities can meet basic daily needs and adapt to the growing challenges of climate change. Built infrastructure in rural settings, like dams, water distribution systems, and treatment plants must be adapted so that they can reliably function under an increasingly broad range of climatic conditions and disruptions. Through these efforts, the engineers, contractors, utilities, and other agencies that lead the siting, design, and construction processes need to ensure that water and sanitation infrastructure is climate resilient. To do so equitably requires the inclusion and centering of rural 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 rural communities.





5. Technology and Innovation

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

Technology and innovations that are accessible and feasible for rural communities are fundamentally important for preparing and responding to the impacts of climate change on rural water and sanitation systems (Christiansen, Olhoff, and Traerup 2011). In this section, technology and innovation are broadly referred to as the application of creative methods and innovative means beyond traditional approaches to reduce vulnerability or increase the resilience of rural water and sanitation systems to the impacts of climate change. Multiple types of water and sanitation technologies are included (e.g., water efficiency and reuse technology and portable sanitation systems) (see Table 5). Technology plays an important role in securing access to clean water and sanitation and enhancing climate resilience in rural areas (Taylor et al. 2024). It can, for example, decrease water demand, provide access to water and sanitation during disruptions, enhance water quality by decreasing wastewater discharges, and more (see Table 5).

For example, technological innovations, like solar-powered water supply, can offer low-cost and reliable drinking and sanitation services in rural areas where homes may be too few or dispersed to justify the cost of centralized infrastructure (REAL-Water 2022). Climate-resilient rural water technologies can complement community-wide centralized water infrastructure and onsite systems that are not connected to larger infrastructure (i.e., decentralized). While conventional built infrastructure like pipelines, reservoirs, and treatment plants (see [Section 4](#)) can be included in the broader definition of technology, the emphasis here is on innovative approaches that extend beyond built infrastructure. Some of the technologies covered here also overlap with the natural infrastructure discussed in [Section 6](#) (e.g., rainwater harvesting). Many innovations in water and sanitation technology are a function of the management structure in place (Howard et al. 2010), which ties this section closely to [Section 7](#).

Technology plays an important role in securing access to clean water and sanitation and enhancing climate resilience in rural areas.

TABLE 5. 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 and fixtures (e.g., high-efficiency toilets) • Leak detection sensors • Advanced metering infrastructure • Rainwater harvesting systems	• Decrease water demand • Free up potable water supplies • Increase resilience to drought • Decrease water and energy costs
Water reuse	• Onsite greywater and wastewater reuse systems • Distributed drinking water filtration systems • Large-scale, centralized wastewater and greywater reuse systems	• Decrease potable water demand • Increase resilience to drought • Diversify water sources • Decrease wastewater discharge; enhance water quality • Access to water during/after disruptions
Sanitation	• Portable nonpipelined sanitation systems • Flood-proof latrines • Composting toilets	• Access to sanitation during/after climate 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) • Flood/drought forecasting systems • Early warning systems for floods	• Better prepare for potential disruptions to water and sanitation • Reduce/mitigate flood and drought impacts

This section highlights four attributes of equitable and climate-resilient technology and innovation for rural water and sanitation systems:

1. equitably implemented sustainable and climate-resilient technologies;
2. cost-effective water-saving technologies for rural households;
3. technologies implemented for large-scale water users and operations that extend benefits to rural communities;

4. water and sanitation technologies are tested and safe before implementation in rural settings.

Throughout this section we emphasize strategies that are culturally appropriate and co-developed with communities. A table at the end of each section includes case examples and online resources such as toolkits, programs, and guides to help rural communities adapt the strategies to local needs and values. However, not all strategies have corresponding case examples in this report. For further details and additional case examples, see the corresponding Section 5 in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).

5.1. EQUITABLY IMPLEMENTED CLIMATE-RESILIENT WATER AND SANITATION TECHNOLOGIES

Attribute description: Sustainable, climate-resilient rural 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 rural 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 rural communities.

To achieve this, **the development of climate-resilient water and sanitation technologies for rural communities requires community engagement with special attention to local culture and values.** For example, the Indigenous Food, Energy, and Water Security and Sovereignty (Indige-FEWSS) program, a University of Arizona research project, is a novel **collaboration between the University of Arizona 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, rural households haul water for drinking, cooking, and bathing from unregulated and contaminated sources, like livestock wells and springs (Litvack 2019). Indige-FEWSS graduate students in collaboration with undergraduate students from Diné College designed a solar-powered, mobile water filtration technology that can clean 1,500 gallons of water per day for 30 households (Figure 7). The engagement and 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 when water and sanitation resources are scarce during severe droughts (Donahue 2024).

FIGURE 7. A Diné College Student Demonstrates Use of the Water Filtration System

Source: Litvack 2019; Photo by Torran Anderson/Institute for Energy Solutions

Sharing knowledge and resources is another strategy for ensuring that rural communities have access to water and sanitation technology (United Nations Framework Convention on Climate Change 2014). Amid renewed interest in rainwater harvesting in the Southern Great Plains in response to extreme heat and variable rainfall patterns, the USDA Southern Plains Climate Hub partnered with the Bureau of Indian Affairs to provide education and guidance on rainwater harvesting technology tailored for Tribes (Southern Plains Climate Hub, n.d.). Approximately 150 members of historically underserved rural communities participated in the program, which also 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 along with the technology itself allowed the community to overcome the lack of knowledge and upfront costs (Voth-Gaeddert et al. 2022). As a result, the rural community increased its resilience to climate impacts by decreasing water scarcity, which also increased adaptability to future climate disruptions.

An example of a resource aimed at increasing access to digital solutions for rural and small water systems in the US Water Alliance’s Advancing Water Equity in Small and Rural Communities: The Role of Digital Solutions (US Water Alliance 2023). Digital solutions refer to smart water technologies that provide water systems with predictive and actionable information to manage operations and infrastructure more efficiently and effectively. For example, remote monitoring technologies that track system operations, equipment, and water flow in real time can support rural water operators and technicians to more effectively manage infrastructure. This is especially true for operators overseeing multiple systems across a wide geographic area. It helps them to better understand real-time processes, risks, and issues within their systems. As climate change intensifies extreme

events, water and sanitation infrastructure are at heightened risk of damage (Taylor et al. 2024; Pacific Institute and DigDeep 2024). This puts poorly monitored water and sanitation systems at an increased risk for failure, biological contamination, leaks, and corrosion because of the lack of ability to anticipate and address problems quickly (US Water Alliance 2023). The guidance includes steps to reduce barriers for small and rural water systems to implement digital solutions. One step is to make water innovations accessible to small systems by providing funding, incentives, and technical assistance from state and the federal governments.

Planning and management strategies that include equity can also help ensure water and sanitation technologies are equitably designed and implemented in rural communities. The [National Water Reuse Action Plan](#), is an example of a planning effort to advance water reuse technologies and enhance community resilience to climate change (US EPA 2019b). The initiative involves multiple actions, one of which is focused on engagement with disadvantaged and rural communities. One of the outcomes of this action was a pilot project that offered technical assistance for assessing and planning for water reuse in rural Idaho and Kansas (Spurlock, Davis, and Chaudhry 2023). After 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 shared wastewater treatment facility. 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 strategy can help rural communities overcome a lack of technical expertise and staff capacity to implement climate-resilient technologies in rural communities (Bertule et al. 2017; Spurlock, Davis, and Chaudhry 2023; Voth-Gaeddert et al. 2022).



Table 6 lists the four strategies for equitable implementation of climate-resilient water and sanitation technologies in rural areas shared in this section. It also includes resources, tools, and case examples to help rural communities explore opportunities for implementation.

TABLE 6. Strategies, Resources, and Case Examples for Equitably Implemented Water and Sanitation Technologies for Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Engage with stakeholders, paying special attention to local values and cultures, when designing and implementing rural water and sanitation technologies and innovations. 2. Develop respectful partnerships between universities, technology companies, and rural communities to co-develop technologies tailored to community needs. 3. Implement knowledge sharing about climate-resilient technologies, especially to communities with unequal access to information. 4. Integrate equity-centered frameworks in the planning and design of technologies.	• Technologies for Adaptation in the Water Sector (United Nations Framework Convention on Climate Change 2014) (1) • Equitable Water Infrastructure Toolkit (River Network 2021) (4) • Advancing Water Equity in Small and Rural Communities: The Role of Digital Solutions (US Water Alliance 2023) (4)	• Navajo Water Project – Herbert’s Story in McNeeley et al. (2025) (page 84–85) (1) • Indigenous Food, Energy, and Water Security and Sovereignty Program (Litvack 2019) (1, 2) • Empowering Community Resilience with Sustainable Energy and Water Reuse Systems Project (Fry 2025) (1, 2) • USDA Southern Plains Climate Hub and the Bureau of Indian Affairs Rainwater Harvesting Project (Southern Plains Climate Hub, n.d.) (3) • Lessons for Optimizing the Adoption of Water Reuse in Underserved Communities: An Output of the National Water Reuse Action Plan, Action 8.5 (Spurlock, Davis, and Chaudhry 2023) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

5.2. COST-EFFECTIVE WATER-SAVING TECHNOLOGIES FOR RURAL COMMUNITIES

Attribute description: Water fixture upgrades, water-saving appliances, and other water-saving technologies are equitably installed to save water and reduce cost burden on utility bills of rural households.

Technologies for water conservation and efficiency are key for saving water, lowering household utility bills, and reducing the costs of securing new water supplies — a growing challenge as climate change impacts water availability (Cooley, Shimabuku, and DeMyers 2022; US EPA 2022b). Water and cost-saving technologies are especially important for rural communities that disproportionately face water affordability challenges and climate change impacts (see Attribute 8.5). For example, some rural communities dependent on groundwater may experience rising costs due to more energy required to extract water from deeper depths. Climate change is tied to an increase in groundwater use and decrease in groundwater recharge and storage, particularly as surface water supplies are constrained (Amanambu et al. 2020; Meixner et al. 2016; Pauloo et al. 2020). Higher rates of pumping and groundwater depletion are already a reality for rural communities and farming operations reliant on the Ogallala Aquifer in the Central US, for example (Hanrahan 2024; Tidwell et al. 2015). When local or regional water costs increase, cost-effective water-saving technologies are important to not only reduce household utility bills, but also for extending limited water supplies.

Equitable and climate-resilient water systems can prioritize water- and cost-saving technologies for rural communities as one method to address affordability challenges. Although rural-specific water-saving technology program examples are limited, the following paragraphs and Table 7 highlight strategies, resources, and case examples of cost-effective and climate-resilient water technology for rural areas.

A strategy to help ensure that rural households most in need of assistance can access water and cost-saving technologies is the **development of water efficiency programs tailored to low-income residents**. An example of a successful initiative is Colorado’s Mile High Youth Corps, which provides income-qualified households with water and energy fixture retrofits, helping them save an average of over \$200 per year on utility bills (Mile High Youth Corps, n.d.). Funded through a combination of federal, state, and private grants, as well as contributions from water utilities within the program’s service area, the initiative extends to both urban and rural regions. Additionally, the program offers career training opportunities, equipping local youth with skills for employment in construction, conservation, and health care industries. Rural communities often face capacity and resource challenges in implementing water efficiency programs (Cooley, Shimabuku, and DeMyers 2022; Shimabuku and Snyder 2022), making this **collaborative partnership model an effective strategy for delivering these technologies to rural areas**.

Another example of a collaborative water efficiency program is the Beyond Lawn Water Efficient Landscape Conversion Program in Eagle County, Colorado, developed by WaterNow Alliance in partnership with local organizations (WaterNow Alliance, n.d.-a). This initiative provides rebates for turf replacement and irrigation technology upgrades. This helps landowners and homeowner associations reduce outdoor water use and lower utility costs while preserving local water resources

that may become scarce with worsening drought in the future (Udall and Overpeck 2017; White et al. 2023; Wlostowski et al. 2021). The program extends existing rebate eligibility beyond the water and sanitation district boundaries in the county. As such, this program serves as an example for how regional water districts can design cost-effective, climate-resilient outdoor efficiency programs to enhance water conservation efforts in rural areas. WaterNow’s [Eagle County Project Summary](#) provides insights into the program’s development, key lessons learned, and strategies for engaging stakeholders in efficient technology rebate programs.

Table 7 lists the three strategies for cost-effective and water-saving technologies for rural households shared in this section. It also includes resources, tools, and case examples to help rural communities explore opportunities for implementation.

TABLE 7. Strategies, Resources, and Case Examples for Cost-Effective Water Saving Technologies for Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Develop water efficiency programs tailored to low-income residents so that they benefit from cost-saving technologies.	• WaterSense Program (US EPA n.d.-g) (1) • WaterNow Alliance Eagle County, Colorado project summary (WaterNow Alliance, n.d.-a) (1, 2)	• Colorado’s Mile High Youth Corps Free Energy & Water Services (Mile High Youth Corps, n.d.) (1, 2) • California’s Income Qualified Energy Saving Assistance Program (California Public Utilities Commission, n.d.) (1) • Resource Central’s outdoor water efficiency incentive programs (Resource Central, n.d.) (2)
2. Partner with community-based organizations to build trust within rural communities and enhance participation in tailored low-income water efficiency programs.		
3. Leverage corporate investments to implement water and cost-saving technologies in rural communities, such as affordable housing complexes.		

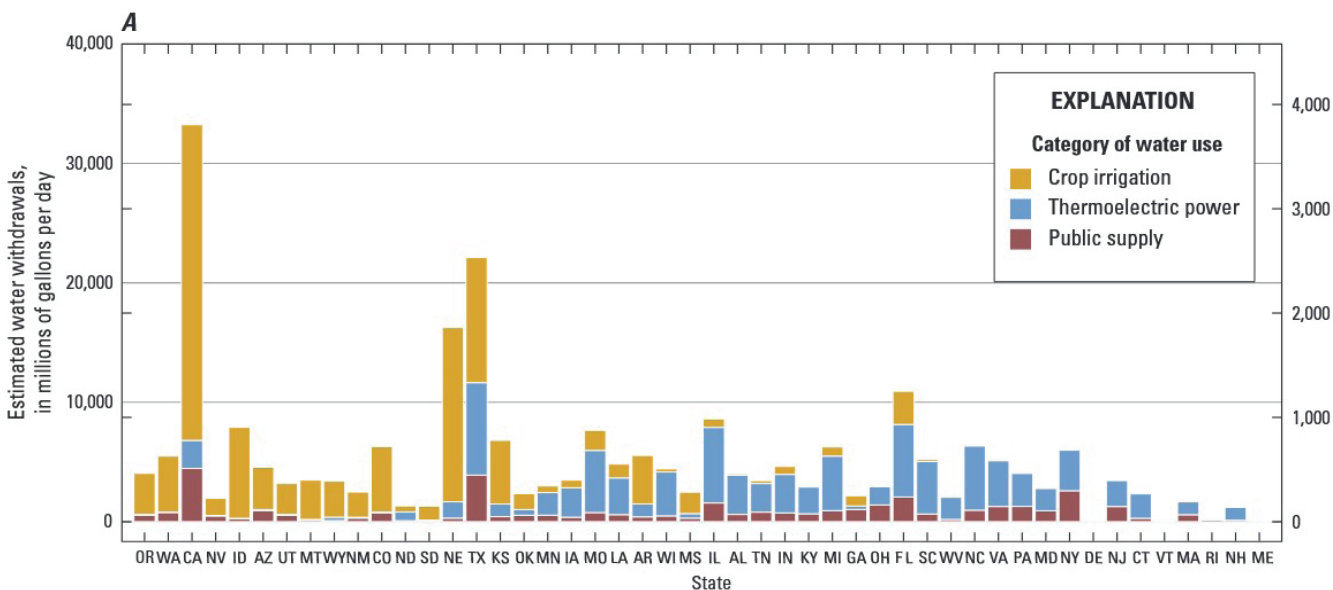
Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

5.3. SUSTAINABLE, EQUITABLE WATER AND SANITATION TECHNOLOGIES FOR LARGE-SCALE WATER USERS AND OPERATIONS

Attribute description: Sustainable water-use and sanitation technologies are implemented for large-scale water users and operations, like commercial and industrial users, and increase equity and climate resilience for rural communities.

Drought, groundwater depletion, and water contamination are all challenges facing US communities, especially rural communities, as climate change continues to intensify extreme weather events (Taylor et al. 2024; Pacific Institute and DigDeep 2024). In rural areas, non-domestic and large-scale water users, like agriculture,¹⁷ make up a large portion of water use. Figure 8 shows model estimates of total water withdrawals for crop irrigation, thermoelectric power, and public supply¹⁸ (which includes domestic as well as commercial, industrial, and institutional water use) by state in 2020 (Medalie et al. 2025). Crop irrigation makes up a significant portion (~86%) of Western US water withdrawals from both surface and groundwater. As such, irrigation in rural areas is an important element to consider when implementing sustainable technologies and innovations.

FIGURE 8. Estimated Total Water Withdrawals by Category and State in 2020



Source: Medalie et al. 2025

Other large-scale operations are also important adopters of sustainable water and sanitation

¹⁷ 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 attribute but is an important consideration for equitable and climate-resilient water technologies for underresourced, small farmers.

¹⁸ Public supply is defined by the United States Geological Survey as “water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections” (Medalie et al. 2025).

technologies and innovations. This can include industrial facilities, data centers, and drinking water and wastewater treatment plants, for example. Climate change impacts to large-scale facilities and operations can create cascading water quality and quantity effects on rural communities. For example, during drought, rural communities may face water scarcity challenges that are made more intense by high rates of irrigation water demand. As another example, more frequent and intense precipitation and flooding can lead to greater chemical contamination of critical water sources due to increased industrial runoff. This can threaten the source water and food gathering areas relied upon by Indigenous and rural communities (Status of Tribes and Climate Change Working Group 2025). This section describes strategies for commercial and other large-scale operation water and sanitation technology uptake to improve rural community resilience to climate change.

A strategy to support rural resilience to climate change is to **establish laws and policies that promote the adoption of water and sanitation technologies among commercial, industrial, and other large-scale water users that benefit rural communities.** For example, under California’s Water Conservation Act of 2009, agricultural water suppliers serving over 25,000 irrigated acres are required to develop and submit an Agricultural Water Management Plan to the Department of Water Resources that details the implementation status of specific efficient water management practices (California Department of Water Resources 2024). The California Department of Water Resources found that implementation of efficient water management practices have improved agricultural water use efficiency in the state, in part due to investment in technologies like new flow meters (California Department of Water Resources 2023).



More efficient use of agricultural water can lessen the pressure on water sources in rural areas, especially during times of drought. In California, the shallow depths of many rural community wells have led to disproportionate drought impacts on rural disadvantaged communities, particularly in the San Joaquin Valley, as domestic wells increasingly run dry (Jasechko and Perrone 2020). Because agricultural wells are often deeper than domestic wells in the US (Perrone and Jasechko 2017), agricultural wells can typically continue drawing groundwater even as shallower domestic and community wells run dry. In addition to overdraw, more frequent and severe droughts are reducing recharge and impacting shallow wells (Payton et al. 2023). Implementing regional or statewide policies that encourage or enforce water saving technologies at the agricultural scale can help reduce water demand, mitigating overdraft and improving rural community access to water and resilience to climate change.

Policies like these can extend to other large-scale operations. For example, regulations to update industrial facilities or wastewater treatment plants with innovations to better prepare for flooding can help to protect water quality in the face of more extreme precipitation events and hurricanes.

To overcome the challenge of upfront costs and ensure technological benefits are equitably distributed, **programs can be put in place to help rural large-scale water users adopt sustainable technologies.** For example, the University of Arizona Cooperative Extension’s [Water Irrigation Efficiency Program](#) provides grants of up to \$1 million per grower to transition from flood irrigation¹⁹ to drip or sprinkler systems, reducing water use by 20% or more (University of Arizona Cooperative Extension 2022). Funded by the American Rescue Plan Act, the program supports farmers who face financial risks and might otherwise be unable to afford these upgrades (Poole 2023). The first 12 projects under the program are expected to save nearly 7,400 acre-feet of water over three years, benefiting the Colorado River Basin’s climate resilience and supporting struggling farmers amid ongoing drought conditions (Poole 2023).

A strategy for centralized rural water and sanitation systems to implement technologies that benefit rural communities is **utilizing innovations to provide clean water or sanitation after climate disruptions.** After the devastation brought by Hurricane Helene in 2024, the wastewater treatment plant in the town of Spruce Pine in rural North Carolina was inoperable due to floodwater damage. As the town began repairing and rebuilding, they deployed mobile wastewater treatment technology called “BluBoxes” to address sanitation needs (Figure 9) (Atwater 2024). One unit can treat 70,000 to 150,000 gallons of waste per day (Integrated Water Services, Inc. 2024). The mobile wastewater treatment plants served areas facing heightened vulnerability in Spruce Pine, including a prison and multiple schools. The BluBoxes were provided by Integrated Water Services, a Texas-based firm that develops water and sanitation products for clients in areas where conventional infrastructure is either unavailable or prohibitively expensive and time-consuming to install (Atwater 2024). The town covered the cost for the BluBoxes, as well as repairs to the sewage treatment plant, through insurance and Federal Emergency Management Agency’s (FEMA) public assistance program (Atwater 2024).

¹⁹ 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).

FIGURE 9. BluBox Mobile Wastewater Unit in Town of Spruce Pine

Source: Atwater 2024; Photo Credit: Will Atwater/North Carolina Health News.

Another option, rural large-scale water users can **partner with NGOs and technology companies to design and pilot water innovations**. For example, Sustainable Conservation is collaborating with three dairy farms in California's San Joaquin Valley and the company Netafim USA to test underground drip irrigation technology. They are using a mix of water and manure to reduce fertilizer use and contamination of local groundwater (Sustainable Conservation, n.d.). Residents in disadvantaged unincorporated communities in San Joaquin Valley face significant challenges obtaining clean drinking water. The majority of them rely 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 raising temperatures and intensifying drought, which can contribute to the concentration of contaminants in groundwater and promote harmful algae blooms in surface waters (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 rural communities, increasing both the farms' and the broader community's resilience to climate change.

The implementation of precision agriculture technologies on farms has the potential to reduce water use and enhance water quality for rural communities, increasing both the farms' and the broader community's resilience to climate change.

Table 8 lists the four strategies for implementation of water and sanitation technologies for large-scale water users and operations to benefit rural communities shared in this section. It also includes resources, tools, and case examples to help rural communities explore opportunities for implementation.

TABLE 8. Strategies, Resources, and Case Examples for Water and Sanitation Technologies for Large-Scale Water Users in Rural Areas

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Establish laws and policies that promote the large-scale adoption of water technologies, offering broad climate-resilience benefits for rural communities. 2. Utilize existing support programs to scale up the implementation of innovations across sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies. 3. Utilize water and wastewater technologies to close gaps in access to services after climate disruptions. 4. Design and pilot large-scale water technologies and innovations collaboratively with nongovernmental organizations (NGOs) and technology companies.	• Climate Hubs (USDA n.d.-f) (2) • Promoting Technology Innovation for Clean and Safe Water: Water Technology Innovation Blueprint — Version 2 * (US EPA 2014b) (+)	• California Department of Water Resources Agricultural Water Management Plans (California Department of Water Resources 2024) (1) • University of Arizona Cooperative Extension Water Irrigation Efficiency Program (University of Arizona Cooperative Extension 2022) (2) • Case Studies that Demonstrate the Benefits of Water Reuse (US EPA 2023a) (2) • Nebraska Extension Master Irrigation Design Summit (UNL Water 2025) (2) • Mobile wastewater technology in Spruce Pine, North Carolina, in response to Hurricane Helene (Atwater 2024) (3) • Pilot underground drip irrigation technology in San Joaquin Valley (Sustainable Conservation, n.d.) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*Some links included in this resource no longer work. This resource is included on an [archived EPA website](#) from 2017.

5.4. TESTED AND SAFE WATER AND SANITATION TECHNOLOGIES

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

Climate change adaptation measures must be carefully tested and evaluated to avoid unintended negative impacts or maladaptation, especially on human health and the environment (Balaji 2023; Schipper 2020). Technological maladaptation occurs when innovations designed to support climate change adaptation unintentionally lead to harmful outcomes (Balaji 2023). In an example from outside the US, Bertana and co-authors showed 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. This threatened and worsened water access for local farmers, increasing their vulnerability to the changing climate (Bertana et al. 2022). As such, equitable and climate-resilient rural water and sanitation includes tested and safe water and sanitation technologies and innovations.

To avoid adversely affecting rural communities with the implementation of well-intended water and sanitation technologies, it is important to **test and prove that the technologies are safe and effective before widespread implementation**. This requires an understanding of the social, economic, and cultural context of the receiving community. This strategy helps to overcome the challenges of maladaptation by integrating local knowledges and the social, cultural, and ecological contexts into the technology design process, ensuring that the solution addresses the root causes of vulnerability and is adaptable to future climate impacts (Bertana et al. 2022; Brill et al. 2022; Christiansen, Olhoff, and Traerup 2011; Schipper 2020).

In Kivalina, Alaska, the Inupiat community piloted the Portable Alternative Sanitation System (PASS) to address the lack of sanitation systems in rural households (see Figure 10). The pilot phase helped ensure the system's effectiveness, affordability, and cultural alignment before broader implementation (Alaska Department of Environmental Conservation 2020; Alaska Native Tribal Health Consortium 2017).

FIGURE 10. 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

A PASS is a portable and affordable in-home sanitation technology for households (Alaska Native Tribal Health Consortium 2017). PASS uses locally sourced water (such as rainwater, melted ice, or hauled water), separates liquid and solid waste, and provides treated water for handwashing, all while centering the community's social, cultural, economic, and physical needs (Alaska Native Tribal Health Consortium 2017). The project is a collaboration between the Alaska Native Tribal Health Consortium (ANTHC) and the Cold Climate Housing Research Center. The system's mobility was designed to address climate change impacts such as rising sea levels, erosion, and extreme storms, ensuring access to resources even during relocation (Alaska Native Tribal Health Consortium 2017). ANTHC engaged directly with homeowners through training and gathered feedback via surveys and interviews, refining the system to better suit local needs. The project tested nine units from 2015 to 2016. By 2020, 56 PASS units had been installed in households in six rural Alaska Native villages (Alaska Department of Environmental Conservation 2020).

When designing and planning rural water and sanitation technologies and innovations, it can be beneficial to apply a **systematic and integrated approach that prioritizes safe and effective solutions, considering the complex and interconnected elements of rural water and sanitation systems**. [Climate Change Adaptation Technologies for Water: A Practitioner's Guide to Adaptation Technologies for Increased Water Sector Resilience](#) includes guidance on prioritizing and selecting

the appropriate climate adaptation technology²⁰ depending on the context and needs. The guide suggests using an integrated planning and management framework such as Integrated Water Resource Management (IWRM), which can be beneficial to understand the many links and potential implications of new climate adaptation water and sanitation technologies in both rural and urban areas (Bertule et al. 2017). IWRM takes a holistic approach water and sanitation management that promotes the coordinated development and management of water, land, and resources to maximize social and economic welfare equitably while promoting ecosystem sustainability (United Nations Environment Programme 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). This strategy helps to addresses key barriers to successful climate adaptation, such as a lack of consideration for local capacity and values, or outdated management frameworks that do not consider the interacting factors in local adaptation when implementing innovations (Wasley et al. 2023).

Table 9 lists the two strategies for testing water and sanitation technology before implementation in rural communities presented in this section. It also includes resources, tools, and case examples to help rural communities explore opportunities for implementation.

TABLE 9. Strategies, Resources, and Case Examples for Tested and Safe Water and Sanitation Technologies for Rural Communities

STRATEGIES	RESOURCE/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Engage the community during the pilot phase of a new technology to understand local conditions, values, cultures, and needs before widespread implementation. 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.	• Climate Change Adaptation Technologies for Water: A Practitioner’s Guide to Adaptation Technologies for Increased Water Sector Resilience (Bertule et al. 2017) (2) • Principles and Practices of Integrated Water Resources Management (Stockholm International Water Institute 2020) (2) • Water Resilience Assessment Framework (CEO Water Mandate 2024) (2)	• Portable Alternative Sanitation System pilot project (Alaska Native Tribal Health Consortium 2017) (1) • Water Reuse Case Study: The Alaska Water and Sewer Challenge (US EPA 2024m) (1)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

20 Climate adaptation technology refers to 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).

5.5. TECHNOLOGY AND INNOVATION SUMMARY

Water and sanitation technologies and innovations offer significant potential to enhance the climate resilience of rural communities. However, 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 rural communities. Strategies like robust stakeholder engagement, equity-centered frameworks, and partnerships are important to ensure that rural communities benefit from technology and innovations. In addition, water efficiency and reuse technologies can reduce costs for rural communities, although challenges like high upfront costs persist. In addition, large-scale water users and operations have a major role in advancing equity and resilience by adopting technologies that reduce water demand and improve water quality for rural communities. This can be facilitated through relevant policies, partnerships, and support programs. Finally, the effective deployment of these innovations requires a deep understanding of rural contexts and a systematic planning approach to avoid maladaptation.





6. Natural Infrastructure

This category describes how nature and natural functions and processes can be used to build and protect equitable, climate-resilient rural water and sanitation systems.

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 2020; 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; 2021b; 2024). NI can play an important role in ameliorating climate change impacts such as erosion, flooding, droughts, and fires through the ecosystem services they provide. It can be designed to support equitable and climate-resilient water and sanitation systems in rural communities (Cohen-Shacham et al. 2016; Langridge et al. 2014; M. Smith 2024).

Although 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 green infrastructure (GI). NBS includes “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).²¹ NBS can include measures such as natural vegetation management and restoration to reduce the impacts of floods and droughts, sand dune restoration to protect land from stormwater surges, and constructed wetlands to control water pollution and mitigate flooding (Oral et al. 2020; Ramírez-Agudelo et al. 2020; US Climate Resilience Toolkit 2024).

Although often used interchangeably with NBS, GI specifically refers to interconnected, constructed 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). Some examples of GI include green roofs, parks, and bioswales (European Commission 2025; Urban Resources Initiative 2016). Green infrastructure stands in contrast to grey infrastructure, which is defined as traditionally engineered solutions and structures such as concrete dams,

²¹ 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).

seawalls, pipes, and water treatment plants (covered in the [Section 4](#)) (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 can be a powerful way to advance equitable climate resilience for rural water and sanitation systems. Projects can be designed to provide multiple benefits, including:

- 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;
- improving human physical, mental, and social health through recreation and exercise opportunities;
- providing aesthetic and spiritual benefits;
- reducing the direct exposure of people and assets to climate change hazards; and
- addressing disproportionate hazard exposure for rural communities (Cooper et al. 2016; Rowe and Bakacs 2012; Simons 2017; Vigerstol et al., 2023; Wolch, Byrne, and Newell 2014).



Despite the myriad ways NI can promote equitable and climate-resilient water and sanitation in rural communities, it is not a panacea. There are multiple challenges involved in the implementation of NI and its ongoing management, which can include insufficient public resources, financing challenges, and planners' preference for conventional engineered or "grey" solutions (Cousins 2024). NI can also produce significant tradeoffs, such as gentrification and displacement, and exacerbate, rather than address, inequality. 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 in rural communities.

This section highlights four attributes of equitable and climate-resilient NI strategies for rural water and sanitation systems. They are:

1. removing constraints for natural infrastructure implementation,
2. centering communities and equity in natural infrastructure planning,
3. natural infrastructure projects proactively remove displacement risks, and,
4. natural infrastructure benefits are valued for achieving equitable climate resilience.

This section also includes strategies, resources, tools, and case examples that can support rural communities implement and maintain equitable and climate-resilient NI. Where possible, we emphasize strategies that have been co-developed with community members. For further details and additional case examples from more urbanized settings, refer to Section 6 on natural infrastructure in [Achieving Equitable, Climate-Resilient Water and for Frontline Communities](#) (McNeeley et al. 2025).

6.1. REMOVING CONSTRAINTS FOR NATURAL INFRASTRUCTURE IMPLEMENTATION

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

NI projects can be designed to increase the resilience of rural communities and their water and sanitation systems to the impacts of climate hazards. However, their uptake relies on supportive governance, policy, legal, and financial systems. Rural communities may face a range of constraints to NI implementation including, but not limited to, a lack of supportive policies and regulations for NI implementation along with challenges coordinating plans, implementation, and maintenance across multiple actors (Boelee et al. 2017; Dhakal and Chevalier 2017; Ershad Sarabi et al. 2019; IJszenga 2021; Matthews, Lo, and Byrne 2015; Roy et al. 2008; Solheim et al. 2021).

Natural infrastructure governance is often complex and can present challenges for the organizations and groups involved. The scale and scope of NI projects often require collaboration between multiple municipal government departments, public and private funders, nongovernmental organizations,

community groups, and residents (Dhakal and Chevalier 2017; FEMA 2021, 2023a; IJszenga 2021; Solheim et al. 2021). Collaborating between many different actors, each of whom may have different responsibilities, priorities, and goals can create governance challenges related to decision making, budget allocations, and management and maintenance (Brill et al. 2022; Boelee et al. 2017; Dhakal and Chevalier 2017; IJszenga 2021; Roy et al. 2008). These governance challenges require innovative strategies so actors can collaboratively design, implement, and maintain NI. As a result, many rural communities may prioritize grey solutions by default. However, NI is often a more cost-effective alternative to grey infrastructure that can simultaneously provide additional environmental and social benefits that grey infrastructure is unlikely to provide such as aesthetic and recreational benefits or improved air quality (Copeland 2014; Dhakal and Chevalier 2017).

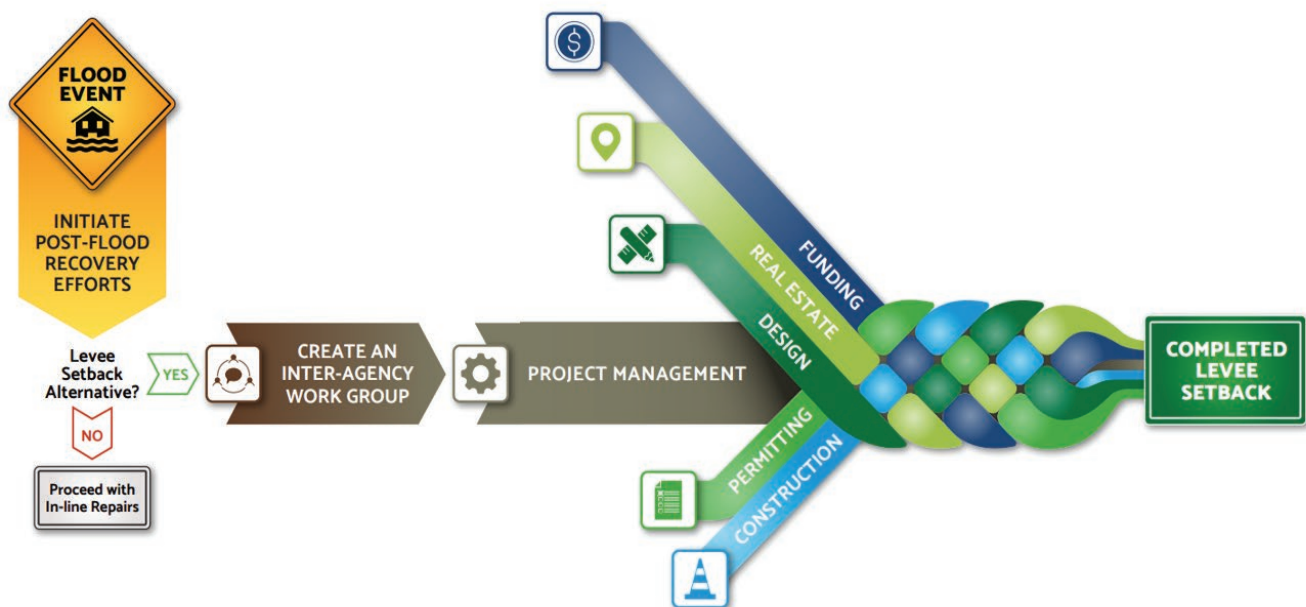
One strategy to overcome governance challenges is to **create integrated NI management plans to coordinate knowledge and information exchange, planning, and management across departments, sectors, and jurisdictions**. Existing guides, such as the [Natural Solutions Initiative Regulatory Mechanisms Toolkit](#), can be used to coordinate NI planning and management within and between rural municipalities and departments (ACT 2024). At the watershed scale, the toolkit includes recommendations for municipalities to work together to support NI uptake. Recommendations include working across jurisdictions to establish growth boundaries and habitat corridors to protect natural areas and collaborating to form watershed-scale integrated stormwater management plans to coordinate land use activities, stormwater management, and ecosystem connectivity across municipalities. These coordinated approaches support NI planning and management between rural communities and, more broadly, enhance regional climate resilience.

Rural communities can also use this toolkit for guidance to **implement policies to overcome constraints to equitable NI project outcomes**, another strategy to overcome governance challenges. At the community scale, the toolkit contains recommendations for zoning and regulatory bylaws and policies to support NI uptake within individual municipalities. These recommendations include creating policies to address climate change adaptation and mitigation, designating Environmentally Sensitive Areas and land uses for development in areas away from riparian corridors. Rural communities can use this type of guide to identify context-specific policies to support NI uptake and increase climate resilience.

Another strategy to overcome governance and collaboration challenges is to **form strong partnerships, coalitions, and interdisciplinary working groups to build NI project support**. For example, in rural Atchison County, Missouri, strong partnerships were established through an interagency work group to design and implement a levee setback (see Figure 11) (FEMA 2023a; Smith 2023). A levee setback is an NI solution wherein a levee is moved further from the body of water it was designed to contain to give floodwater more space to move to reduce flood risk, improve wildlife habitat, and increase the resilience of the community to climate impacts (FEMA 2023a). Project partners included the Missouri Department of Conservation, the Missouri Department of Natural Resources, the Missouri River Recovery Program, the Missouri State Emergency Management Agency, the Natural Resources Conservation Service, Northwest Missouri Regional Council of Governments, The Nature Conservancy, and the US Army Corps of Engineers. These partners also worked with residents, landowners, and local government partners to support planning for and implementation of the levee setback.

Individuals from each partner organization brought unique skills to the project. This meant that partners were able to distribute project tasks in line with respective expertise. Some partners addressed grant applications and funding needs while others supported environmental assessments and land acquisitions. Others acted as conveners to facilitate conversations between partners and maintain project momentum. The local levee district, with existing relationships with the community, navigated engagement with residents. In this way, barriers to NI implementation such as funding challenges, complex land ownership issues, and governance and coordination challenges, were addressed by partners most suited for the task (FEMA 2023a).

FIGURE 11. Development of an Inter-Agency Work Group



Source: The Nature Conservancy 2021

A strategy for rural communities to address financial barriers to NI implementation is to **use innovative and diverse funding sources appropriate to the local context**. For example, Placer County and the Tahoe National Forest entered an agreement to implement the French Meadow Forest Restoration and American River Headwaters Project in California. This is a rural NI project that used innovative and diverse funding sources. The American River, located within the Tahoe National Forest, is the source water supply for downstream rural communities. Project plans included NI elements such as meadow restoration and reforestation to protect the American River and water supplies from climate impacts like wildfire (Storey et al. 2019). The project's inclusion of private and public lands opened multiple funding opportunities. For example, local, state, and federal agency funding was 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). Funding was also provided by private donors including beverage companies and landowners (Storey et al. 2019; Vigerstol et al. 2023). Sales from wood products and biomass collected during thinning provided additional revenues for the project (Storey et al. 2019; Vigerstol et al. 2023).

Table 10 lists the four strategies for rural communities to address constraints to NI implementation shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 10. Strategies, Resources, and Case Examples to Address Constraints to Natural Infrastructure Implementation in Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Create integrated natural infrastructure (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 build NI project support and consensus. 4. Use innovative and diverse funding sources appropriate to the local context.	• Natural Solutions Initiative Regulatory Mechanisms Toolkit* (ACT 2024) (1, 2) • Building Community Resilience With Nature-Based Solutions: Strategies for Success (FEMA 2023a) (1, 3, 4) • Procurement Guide for Nature-Based Solutions (Leung, Woiwode, and Smith 2018) (4) • Wetland Reserve Easements (Natural Resources Conservation Service 2025b) (4)	• Large Scale Levee Setback Playbook (The Nature Conservancy 2021) (2, 3) • Headwaters Economics flood risk pilot in Three Forks, Montana (Smith 2021) (3) • Coalition between the Quileute Tribe and the Wild Salmon Center to Restore the Quillayute River (DeNies 2019) (3) • The French Meadow Forest Restoration and American River Headwater Project (Storey et al. 2019) (3, 4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*International Example

6.2. CENTERING COMMUNITIES IN NATURAL INFRASTRUCTURE PLANNING

Attribute description: Rural communities and equity are centered in NI planning for climate resilience.

Centering communities and equity in NI planning is a fundamental step in advancing equitable and climate-resilient water and sanitation systems in rural communities (Brill et al. 2022; Willems et al. 2020; Wilker, Rusche, and Rymsa-Fitschen 2016). Including rural community members in each planning stage — particularly those who have been historically underserved — can help ensure that NI projects reduce risks, address broader community needs, and support community ownership of the project once implemented (FEMA 2023a). When rural communities are centered in NI planning and decision making, projects are more likely to advance community needs (Bradley 2023).

While essential, community engagement can be difficult to implement in a meaningful way. For instance, conventional community engagement approaches are often top-down and one-directional, where planners convey information to residents or stakeholders but do not include mechanisms for receiving or integrating community feedback (Everett, Adekola, and Lamond 2023). Top-down approaches are common in NI, and this approach typically does not build in mechanisms to capture the needs or priorities of rural community members (Berni et al. 2022).

When rural communities are centered in natural infrastructure planning and decision making, projects are more likely to advance community needs.

This section provides strategies, resources, tools, and case examples to help those implementing NI projects to better center rural communities. For a list, see Table 11. For more on community engagement, see [Section 10.2](#) and [Section 7.2](#).

One strategy to center equity in rural NI projects is to **incorporate definitions and principles of justice and equity**. The [Principles for Just and Equitable Nature-Based Solutions](#) guide can be consulted to incorporate justice and equity principles into rural NI projects (Stockholm Environment Institute et al. 2022). The guide defines “just NBS” (meaning equitable NBS) as “harnessing the power of nature and people to transform the social, political, and economic drivers of socio-spatial inequality and environmental degradation into opportunities to create progressive, cohesive, antiracist, and social-ecologically sustainable communities” (Stockholm Environment Institute et al. 2022; Cousins 2021). The guide also outlines dimensions of social equity for NI, which include fair distribution of costs and benefits, inclusive decision making, and the integration of stakeholder knowledge, norms, and values in processes and plans. It emphasizes the importance of creating conditions that allow stakeholders to participate meaningfully, gain recognition, avoid or reduce potential losses, and benefit from outcomes. Additionally, the guide outlines five principles for just and equitable NI that can be incorporated in each project stage. These are:

1. Ensure that design, governance, and implementation processes are inclusive and transparent.
2. Tackle root causes of marginalization, inequality, and injustice at all stages.

3. Limit economic and non-economic losses and avoid the unjust redistribution of risks and costs.
4. Prioritize interventions for the most at-risk places and communities.
5. Devise and use valuation and measurement tools that assess social and political change and consequences.

While including these definitions and principles may not, on their own, contribute to increased climate resilience, they can help ensure that the climate resilience benefits provided by NI accrue to rural community members in just and equitable ways. By incorporating definitions and principles of justice and equity throughout NI plans and evaluations, rural communities can design NI projects that simultaneously advance climate resilience and equity (Stockholm Environment Institute et al. 2022).

Another strategy to center rural communities in NI planning is to **use community-led decision making for NI planning and implementation**. Community-led decision making centers the knowledge, needs, and expertise of residents in project design and implementation (Bradley 2023). For example, the Quileute Tribe led a collaborative NI project for river restoration. The Quileute Reservation is located at the mouth of the Quillayute River in rural Washington State. The project partners included state and federal fish and wildlife agencies, the National Park Service, and the Army Corps of Engineers (DeNies 2019; Wild Salmon Center 2022). The Tribe's place-based knowledge and the expertise of Tribal scientists guided every stage of research, planning, and implementation for the river restoration project. One example of how the community-led decision making contributed to NI implementation was when the Tribe proposed re-introducing logjams into the river.

Natural logjams, formed by the accumulation of naturally felled old-growth trees, serve as critical habitat for healthy salmon populations and help slow the river flow during rainfall events. In the past, many logjams were removed by loggers seeking clear navigation paths and by restorationists who, at the time, believed logjam removal would support salmon migration (Bisson et al. 1987; Chui 1999). This resulted in fish habitat loss and exacerbated flood conditions during storms, which inundated the Tribal community of La Push. Tribal scientists discussed their concerns and priorities with project partners and proposed the implementation of engineered logjams to protect the village from flood impacts and maintain healthy salmon populations. Community-led decision making helped ensure the knowledge and needs of the Quileute Tribe were understood by project partners and were centered in project plans. Members of the Tribe were also trained to lead the restoration efforts and construct logjams, exemplifying an additional way communities can be involved in project implementation (DeNies 2019; Wild Salmon Center 2022).

Another strategy to center communities and equity in rural NI plans and implementation is to **incorporate transparency, trust building, and mutual learning in community engagement**. The water utility in rural Harpers Ferry, West Virginia, partnered with the community to create a source water protection plan for the Elks Run River (River Network and WaterNow Alliance 2021). Through collaboration and mutual learning, the utility and community members develop a set of voluntary best management practices that include NI elements. These best practices included planting trees and grasses along waterways to filter runoff and protect source water, increasing climate resilience at household and community scales. The Harpers Ferry Water Commission also asked the town

council to open two seats to represent broader community voices in the source water protection plan (River Network and WaterNow Alliance 2021). By taking steps to become more accessible to and inclusive of the community in planning, decision making, education, and action, the utility developed greater trust with the community, and increased transparency of the planning process. As a result, Harpers Ferry was designated as a [Source Water Community](#), an American Water Works Association award given to water utilities that partner with communities on source water protection plans (West Virginia Rivers 2023).

Another strategy to center communities and equity in NI plans is to **form partnerships with trusted individuals or organizations**. Local governments or other implementors of NI projects can form partnerships with local officials, academic institutions, community interest groups, or other individuals or organizations that are widely trusted by the local community. Such partnerships can help project implementors reach and engage a broader range of community members (Shakesprere et al. 2021). The [Stakeholder Engagement Guide for Nature-Based Solutions](#) outlines strategies rural communities can use when entering partnerships to improve community engagement and representation in NI planning. These strategies include, but are not limited to:

- build long-term relationships and trust;
- co-create rather than impose;
- recognize mutual benefits;
- remove barriers to engagement;
- formalize relationships;
- ensure adequate financial support; and
- appoint well-trained, knowledgeable facilitators.

These strategies can serve as a guide for project implementors and their partners to work toward equitable community engagement and representation to advance climate-resilient NI projects.

Given that community members may not be familiar with or may be skeptical of outside institutions, partnerships with trusted local individuals or organizations can help ensure that community voices are equitably centered in project plans (FEMA 2020). Resources such as [A Guide to Supporting Engagement and Resiliency in Rural Communities](#) offer partnership recommendations for government agencies or other outside institutions to equitably advance NI and/or climate resilience projects (FEMA 2020). The guide includes a list of questions for community partnership building. Implementors seeking a community-backed process should ask:

1. Who needs to be involved and who should we call to introduce ourselves to? Are there local experts or community organizers who have led past projects that will have important insights, and can we meet with them?
2. What are your community's safety, resiliency, and hazard mitigation goals? What's worked for your community before, and what are the obstacles that prevented you from doing more?
3. What's important to the people that live here, and what do they want to make sure is here for their grandchildren's children?

These questions can be used by project implementers as a guide to better understand rural community members' experiences and concerns. This can lead to the creation of locally-appropriate NI projects for equitable climate resilience (FEMA 2020).

Table 11 lists the four strategies for centering communities and equity in rural NI planning shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 11. Strategies, Resources, and Case Examples for Centering Rural Communities and Equity in Natural Infrastructure Planning

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Incorporate definitions and principles of equity and justice in natural infrastructure (NI) projects. 2. Use community-led decision making for NI planning and implementation. 3. Incorporate transparency, trust building, and mutual learning in community engagement. 4. Form partnerships with trusted individuals or organizations.	• Principles for Just and Equitable Nature-Based Solutions* (Stockholm Environment Institute et al. 2022) (1) • Stakeholder Engagement Guide for Nature-Based Solutions (Brill et al. 2022) (2, 3) • Exemplary Source Water Protection Award (American Water Works Association, n.d.) (3) • Guide to Supporting engagement and resiliency in rural communities (FEMA 2020) (3, 4)	• Coalition between the Quileute Tribe and the Wild Salmon Center to Restore the Quillayute River (DeNies 2019) (2) • Community-Utility Partnership in Harpers Ferry, West Virginia (River Network and WaterNow Alliance 2021) (2, 3) • Community Lessons for Successful Nature-Based Solutions Implementation* (Purata, Rodríguez, and Lomeli 2023) (2, 3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*International Example

6.3. NATURAL INFRASTRUCTURE PROJECTS PROACTIVELY REMOVE DISPLACEMENT RISKS

Attribute description: Displacement risks of rural NI projects are identified and addressed at the outset.

While implementing NI can improve the climate resilience of rural water and sanitation systems, it can also produce tradeoffs such as environmental gentrification and/or the displacement of households or communities. “Environmental (or green) gentrification” refers to processes where environmental or sustainability practices 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, may come at the expense of rural community members who can no longer afford to live in their homes or neighborhoods (Dale and Newman 2009).

To help ensure that the climate resilience provided by NI projects accrues to all community members, it is important to proactively integrate anti-gentrification and displacement strategies through every stage of the project. Although proactively removing displacement risks linked to NI does not, in and of itself, contribute to more climate-resilient water and sanitation systems, it is a critical step toward guaranteeing the climate resilience provided by NI can equitably accrue to all community members. Table 13 includes resources and tools to mitigate gentrification and displacement risks and promote equitable NI project outcomes. While not specifically focused on rural communities, many of these strategies can be tailored to fit rural contexts.

One strategy to proactively remove displacement risks is to **use existing toolkits to help identify local risk factors for displacement**, which can then help communities to mitigate those risks. For example, the Trust for Public Land developed a toolkit that outlines risk factors for green gentrification and anti-displacement strategies (Rigolon 2024). The document outlines how NI features such as new tree plantings and green stormwater infrastructure can increase displacement risks (see Table 12). These NI features can contribute to displacement risk because the addition of new green amenities can increase the desirability of an area and raise property values. This process disproportionately impacts long-term residents, low-income residents, renters, and communities of color. The guide outlines the risk factors for green gentrification and displacement that are found at the neighborhood scale, such as a lack of existing green space and proximity to other gentrifying neighborhoods. While the guide does not include a comprehensive list of NI actions and their relative displacement risk, it can serve as a starting point rural communities can use to understand, identify, and mitigate displacement risks to help ensure that rural residents can afford to remain in their homes and experience the enhanced climate resilience provided by NI.

TABLE 12. 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 ^{101–106} and Washington, D.C.'s 11th Street Bridge Park. ⁹⁹

Source: Excerpted from Rigolon 2024

Another strategy to proactively remove displacement risk is to **implement locally appropriate and feasible anti-gentrification and displacement policies and practices prior to project construction**. It is more effective to prevent gentrification and displacement with supportive policies and practices in place prior to NI implementation (Will 2019). The Trust for Public Land’s toolkit includes anti-displacement practices, or actions, for a broad range of local actors including communities and nonprofits, economic development agencies, planning and housing agencies, funding agencies, green space agencies, and cross-agency collaborations. Among these actions are:

- developing partnerships for affordable housing;
- inclusionary zoning;
- municipal ordinances to protect existing affordable housing, community organizing; and
- community benefits agreements.

Another toolkit titled [Community-Centered Solutions for Green Gentrification and Displacement](#) centers the Black, Indigenous, other people of color, and low-income residents and communities that face the most extreme climate impacts (River Network 2024). The toolkit includes strategies that rural communities can implement to address gentrification and displacement risks. These include:

- building coalitions and partnerships with organizations and community groups with similar goals and values,
- creating a toolbox of equitable development strategies with the community,
- long-term engagement, and
- applying an equity lens to all planning frameworks and funding processes.

The guide includes links to similar toolkits, funding resources, policies, and anti-displacement plans that rural communities can use to support this work. While many of the examples are urban, rural communities can use these guides to review and select locally feasible and appropriate anti-displacement strategies. These efforts help ensure the climate-resilient water and sanitation benefits of NI do not come at the expense of equity.

Table 13 lists the two strategies for proactively removing displacement risks from rural NI projects shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 13. Strategies and Resources to Proactively Remove Displacement Risks from Natural Infrastructure Projects in Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Utilize and adapt existing toolkits to identify local risk factors for displacement.	• Green Gentrification Risk Factors and Anti-Displacement Options (Rigolon 2024) (1, 2)	• None found
2. Implement locally appropriate and feasible anti-gentrification and displacement policies and practices prior to project construction.	• Community-Centered Solutions for Green Gentrification and Displacement (River Network 2024) (2)	

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 rural water and sanitation are used in decision making.

There are many ways to value the benefits provided by NI. This section references both economic valuation and nonmonetary valuation. With respect to NI, economic valuation refers to a monetary value that society assigns to a given environmental quality or ecosystem service (Brill et al. 2023). While this valuation approach can be useful to illustrate the benefits of NI to different sectors or funders, it is not well suited for all contexts. For instance, when working with cultures that may not assign monetary value to natural systems, nonmonetary approaches may be more suitable (Brill et al. 2023). Non-monetary valuations of NI can assign value to the ecosystem services provided by NI in either quantitative (e.g., the number of people affected) or qualitative (e.g. poor, good, excellent) estimates (Martin and Mazzotta 2018).

It is difficult to communicate the full range of project benefits and tradeoffs through a single valuation system, as any single approach will highlight certain outcomes while obscuring others (Bassi et al. 2020). For example, one valuation framework may illustrate the value of ecosystem services like water quality improvements and disaster risk reduction, but leave out other benefits, such as long-term climate resilience or impacts on local livelihoods (Kuhl and Boyle 2021). Each valuation approach is often best at measuring benefits and tradeoffs at specific spatial and temporal scales, potentially making it challenging to capture the full spectrum of benefits and tradeoffs of NI projects that can affect change across a broad range of scales (Brill et al. 2023). Because of this variation, it is important that rural communities select context-appropriate valuation methods that reflect local values and needs.

Valuation can help to demonstrate the contribution of NI to equitable and climate-resilient water and sanitation systems, potentially supporting NI uptake (Mok et al. 2021; USDA n.d.-b). Valuation approaches can be used to understand the economic feasibility of projects for a rural community, support decision making, and increase public and funder support (Mok et al. 2021; Vandermeulen et al. 2011; Van Oijstaeijen, Van Passel, and Cools 2020; Wild, Henneberry, and Gill 2017; Wilker and Rusche 2014). Rural communities can also use valuation methods to understand tradeoffs for different groups and to adjust project design and implementation to help ensure that benefits accrue equitably.

One strategy to help improve equitable, climate-resilient outcomes from NI projects is to **utilize comprehensive economic valuation methodologies that center climate resilience, human and ecological well-being, and benefits for multiple sectors and stakeholders**. For example, the Sustainable Asset Valuation (SAVi) methodology “uses a combination of system dynamics and project finance modeling to capture the full costs of environmental, social, economic and governance risks” (International Institute for Sustainable Development, n.d.). The International Institute for Sustainable Development, in collaboration with Wetlands International Africa used the SAVi methodology to analyze the viability of an NI project to restore the wetland and mangroves in the Saloum Delta in rural Senegal. The SAVi assessment was used to demonstrate the importance of NI interventions to sustain and support regional livelihoods and development in the face of ecosystem degradation and climate change. The delta’s wetland and mangroves are an important economic resource for local communities because they provide valuable food and fuelwood for subsistence and income generation (Bassi et al. 2020). These resources are considered ecosystem services or benefits that residents derive from the wetland and mangroves.

One strategy to help improve equitable, climate-resilient outcomes from natural infrastructure projects is to utilize comprehensive economic valuation methodologies that center climate resilience, human and ecological well-being, and benefits for multiple sectors and stakeholders.

Climate change and unsustainable use of mangroves in the wetland are causing coastal erosion and salination, which compromises the livelihoods of residents. The SAVi methodology determined the economic valuation of the ecosystem services of the delta’s wetlands and mangroves for local livelihoods and regional development, including co-benefits such as income generation. The framework demonstrated that without NI implementation, such as mangrove reforestation, the quality of the wetland will decrease over time, leading to consequences for local livelihoods and human well-being (Bassi et al. 2020).

Other rural communities can use comprehensive valuation methodologies to understand the impacts of NI projects on climate resilience and community well-being and to build project support.

Understanding the benefits and tradeoffs of NI through an equity lens is an important step to advance equitable and climate-resilient water and sanitation. However, many valuation models on

their own do not explicitly center equity nor tradeoffs. Accordingly, another strategy to center equity in NI valuations is to **use complementary tools to understand and communicate the benefits and tradeoffs of NI projects for rural communities**. Rural communities interested in NI projects can use existing resources such as the [International Union for Conservation of Nature \(IUCN\) Global Standard for Nature-based Solutions self-assessment tool](#) in tandem with valuation methods to better understand and communicate the benefits and tradeoffs of NI plans. The tool is based on the [IUCN Global Standards for Nature-based Solutions](#) report, which outlined eight criteria and associated indicators for equitable NBS. The guide outlines three criteria to equitably balance tradeoffs, which include:

1. the potential costs and benefits of associated trade-offs of the NBS interventions are explicitly acknowledged and inform safeguards and any appropriate corrective action;
2. the rights, usage of, and access to land and resources, along with the responsibilities of different stakeholders, are acknowledged and respected; and
3. the established safeguards are periodically reviewed so that mutually agreed trade-off limits are respected and do not destabilize the entire NBS.

NI project implementers in rural communities can use the guide and self-assessment tool to understand and evaluate project tradeoffs through a community-centered equity lens. This approach can help communities balance priorities for climate-resilient water and sanitation with equity-centered principles that maximize benefits and minimize tradeoffs for community members (International Union for Conservation of Nature 2024).

Another strategy to improve decision making around NI projects is to **incorporate nonmonetary valuations that center equity**.

One example of this strategy in action is from the Klamath River Renewal Project in Oregon and northern California, which is the largest dam removal initiative in US history (Canon 2025). Over the last century, the construction of four dams along the 263-mile river displaced the Hoopa, Karuk, Klamath, Modoc, and Yurok Tribes from their homelands. The Karuk and Yurok Tribes petitioned for dam removal, which resulted in an agreement between Tribal and state governments and federal agencies in 2020 to remove the dams. The NI project was designed to revitalize the river's ecosystem, a process that included dam removal, vegetation restoration, and the relocation of culturally and ecologically significant native turtle species. These efforts aimed to create a more equitable and climate-resilient future for the Tribes that have relied on the river's ecosystem services for generations (Canon 2025).

Another strategy to improve decision making around natural infrastructure projects is to incorporate nonmonetary valuations that center equity.

While economic analysis was used to outline the benefits of the project, the valuation assessment also used nonmonetary valuations. This included assessments of how the dam removal would support Tribal livelihoods and cultural practices. For example, the nonmonetary portion of the assessment found that dam removal would increase Klamath Tribes' – the Klamath, the Modoc, and the

Yahooskin-Paiute people, known as mukluks and numu (the people) – access to traditional lands and expand opportunities to engage in traditional cultural practices (US Department of the Interior, et al., 2013). This type of assessment captures benefits that exist outside of monetary assessments yet are vital to the Tribes and their resilience. Non-monetary valuations can be used on their own or in addition to economic valuations, as appropriate, to help ensure the cultural values and needs of local communities are represented and factored into decision making.

Table 14 lists the three strategies for rural NI valuation shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 14. Strategies, Resources, and Case Examples for Natural Infrastructure Valuation

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Utilize comprehensive economic valuation methodologies that center climate resilience, human and ecological well-being, and benefits for multiple sectors and stakeholders. 2. Use complementary tools to understand and communicate the benefits and tradeoffs of NI projects for rural communities. 3. Incorporate nonmonetary valuations that center equity.	• WaterProof (The Nature Conservancy, n.d.-b) (1) • SAVi (International Institute for Sustainable Development, n.d.) (1) • Nature-based Solutions (NBS) Benefits Explorer (CEO Water Mandate, n.d.) (1, 2) • International Union for Conservation of Nature (IUCN) Global Standards for Nature-Based Solutions (International Union for Conservation of Nature 2020) (2) • IUCN self-assessment tool (International Union for Conservation of Nature, n.d.) (2) • InVEST (Integrated Valuation of Ecosystem Services and Trade-Offs) (Ecosystems Knowledge Network, n.d.) (2) • Benefit Accounting of Nature-Based Solutions for Watersheds (Brill et al. 2023) (2)	• Sustainable Asset Valuation (SAVi) of Senegal’s Saloum Delta* (Bassi et al. 2020) (1) • Klamath River Renewal Project (National Fish and Wildlife Foundation 2025) (1, 3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*International Example

6.5. NATURAL INFRASTRUCTURE SUMMARY

Natural infrastructure can be designed to support equitable and climate resilient water and sanitation systems in rural communities. While not every strategy outlined in this section will be appropriate for all rural communities, they can be used as a guide to generate ideas for context-appropriate and locally tailored NI. Governance, policy, legal, and financial constraints to NI implementation can be removed to create more supportive conditions for NI projects. Communities and equity can be centered in each stage of NI planning and implementation to help ensure the needs and priorities of rural community members are meaningfully addressed. Potential displacement risks from NI projects can be identified and avoided prior to implementation. This will allow rural community members to remain in their homes and benefit from the enhanced climate resilience provided by NI. Finally, the potential benefits and tradeoffs of NI projects can be assessed through economic valuation, nonmonetary valuation, or other context-appropriate approaches, to understand how projects will impact equity and climate resilience and to guide decision making.





7. Management and Planning

This category describes how equity is centered in the way source water protections, community input, financial sustainability, climate impacts and risks, cross-sector coordination, and monitoring and evaluation are incorporated into rural planning and management of water and sanitation.

Equitable and climate-resilient water and sanitation require that management and planning empower communities to withstand, adjust, and evolve amid the uncertainties and challenges posed by climate change (WaterAid, Australian Aid, and Water for Women 2021). Although climate change is increasingly being incorporated into water resource management and planning, this is not always standard nor is it always straightforward (Kolokytha, de Oliveira Galvão, and Teegavarapu 2017; John et al. 2020). Small systems in rural areas often struggle with limited financial, technological, and managerial skills and resources, hindering their ability to manage current challenges and plan for escalating climate-driven disasters (Taylor et al. 2024). 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 rural communities.

This section includes six attributes of water and sanitation management and planning that center equity and are critical for climate-resilient outcomes for rural communities:

1. source water and environmental protections,
2. centering rural communities in plans and programs,
3. rural water and wastewater utilities financially sound in the face of climate change,
4. rural water and sanitation providers prepare for climate disasters and inequitable impacts,
5. cross-sectoral coordination, and
6. monitoring and evaluation.

Included at the end of each attribute is a table with a compilation of resources, toolkits, and case examples. For additional information and examples of equitable and climate-resilient management and planning, see the corresponding Section 7 in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).

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

Attribute description: Source water protections are part of water and sanitation planning and management to increase rural community resilience to climate change.

Millions of people lack access to safe water and sanitation services, with source water contamination a contributing factor (US Water Alliance 2017). 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 2015b). Source water protection involves reducing or preventing potential risks and impacts to drinking water supplies (American Water Works Association 2018). Climate change is intensifying multiple phenomena that can negatively impact the quality and quantity of source water, such as extreme drought, flooding, wildfire, extreme temperatures, sea level rise, and storms (Marvel et al. 2023). These impacts disproportionately affect rural communities who often face limited resources and may depend on private wells and septic systems for their drinking water supply (Taylor et al. 2024). This attribute includes strategies to support rural communities to incorporate source water protection into plans and programs to increase climate resilience.

Rural communities can strengthen source water protection by **developing locally tailored plans with support from technical assistance providers or state agencies**. Planning efforts for proactive protection of source water can best serve rural communities if the process includes direct engagement of community members and local organizations. For example, the [Source Water Protection Program](#) is a collaborative initiative led by the National Rural Water Association in partnership with the USDA Farm Service Agency. This program empowers local communities to safeguard surface and groundwater sources used for drinking water from pollution in rural areas, which face substantially higher rates of water quality violations than urban areas (Allaire, Wu, and Lall 2018). By hiring experienced rural source water technicians, the Source Water Protection Program facilitates partnerships among farmers, ranchers, federal and state agencies, and local organizations to develop customized source water protection plans (USDA n.d.-c). Innovative approaches, such as the use of augmented reality in public education (Figure 12), are helping engage wider audiences and deepen understanding of source water protection efforts (National Rural Water Association 2020b). Although not specifically focused on climate resilience, these voluntary, community-driven plans can support rural communities in addressing unique challenges and protect source water amid increasing climate threats.

FIGURE 12. Interactive, Augmented Reality Sandbox Used by Pennsylvania’s Rural Water Association’s Source Water Protection Specialist to Educate the Public



Source: National Rural Water Association 2020

To advance climate resilience and equity while addressing uncertainty, many rural water managers and planners must deal with water scarcity (Udall and Overpeck 2017; 2017). This challenge is especially pronounced in the Western US due to climate change-related declines in snowpack and extreme drought periods (Siirila-Woodburn et al. 2021; Marvel et al. 2023). Water and sanitation plans and programs can include climate adaptation actions like **increased storage, managed aquifer recharge, demand reduction programs, and real time modeling** (Siirila-Woodburn et al. 2021). For example, for rural, low-income communities in California’s Central Valley, managed aquifer recharge has the potential to provide multiple hydrological, socioeconomic, and ecological benefits. By increasing groundwater supply, it can enhance equitable access to groundwater resources for rural and impoverished communities while also supporting groundwater-dependent agriculture (Marwaha et al. 2021). For more information on strategies related to rural water and sanitation technologies, see [Section 5](#).

Water planners can also protect rural source water by using strategies that address uncertainty and translate hydrologic data into actionable policies. **Co-production approaches that involve scientists, managers, and community stakeholders can create decision-support information and tools tailored to rural communities’ source water challenges** (McNeeley et al. 2018; Siirila-Woodburn et al. 2021). For example, the Eastern Shoshone and Northern Arapaho Tribes on Wyoming’s Wind River Indian Reservation collaborated with universities and agencies to develop drought early-warning tools and a drought preparedness plan, based on the Tribes’ priorities, that tailored solutions for source water protection (McNeeley et al. 2018; 2020).

Finally, managers and planners can enhance rural source water protection by **promoting education and awareness programs for private well testing** to address groundwater safety amid climate risks. Many private well users face inadequate protections from Safe Drinking Water Act violations (Schmitt et al. 2024) and lack the resources or knowledge for regular testing (Flanagan et al. 2016). Climate impacts like heavy rainfall, drought, and wildfires further threaten well safety (Pacific Institute and DigDeep 2024; Pauloo et al. 2020). Governments can offer education and resources to help private well owners learn about proper practices for safe water. For example, [Delaware's Division of Public Health](#) offers a financial assistance program for homeowners with private wells to receive free test kits (Delaware Health and Social Services 2023). The EPA provides [resources for private drinking well programs by state](#) (US EPA 2015g).



Table 15 lists the four strategies for equitable, climate-resilient rural source water protections shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 15. Strategies, Resources, and Case Examples for Equitable, Climate-resilient Rural Source Water Protection

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Develop locally tailored source water protection plans by leveraging existing support programs that connect community members and local organizations in collaborative, proactive efforts to safeguard water quality. 2. Include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security. 3. Collaborate with rural communities, scientists, and managers to co-produce tools, plans, and programs that safeguard source water. 4. Integrate education, awareness, and support for private well water quality testing into management frameworks.	• Source Water Protection Program (US EPA 2024j) (+) • Source Water Protection Justification Toolkit (American Water Works Association 2018) (+) • Environmental Justice Screening and Mapping Tool* (US EPA n.d.-c) (+) • Climate and Economic Justice Screening Tool* (Council on Environmental Quality, n.d.) (+) • Source Water Protection Program (National Rural Water Association 2020b) (1) • The Source Water Collaborative, including map of local, state and regional source water protection collaborations (Source Water Collaborative, n.d.) (1) • Guidance for rainwater harvesting in rural areas (Chenkin 2025) (2) • Private Drinking Water Well Programs in Your State (US EPA 2015g) (4) • RCAP Private Well Program (Rural Community Assistance Partnership, n.d.-b) (4) • Free information and advice about private wells (PrivateWellClass.org, n.d.) (4) • California Water Shortage Vulnerability Tool (California Department of Water Resources, n.d.-b) (1, 4)	• Village of Cloudcroft, NM potable reuse project (Corum 2017) (2) • Development of Innovative Monitoring and Analysis Strategies for Rural Enhanced Aquifer Recharge Structures (US EPA n.d.-d) (2, 3) • Wind River Reservation partnership to develop climate adaptation and source water protection planning (McNeeley 2020) (3) • State of Massachusetts Guidance, Water Quality & Testing, and Other Resources for Private Wells (Massachusetts Department of Environmental Protection, n.d.) (4) • Delaware Department of Environmental Health Financial Aid Program for Private Well Owners (Delaware Health and Social Services 2023) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*The Environmental Justice Screening and Mapping Tool and the Climate and Economic Justice Screening Tool are no longer available as of early 2025. The links provided to these resources in the table are to non-federal versions of the tool provided by the [Public Environmental Data Partners](#).

7.2. RURAL COMMUNITIES CENTERED IN CLIMATE, WATER, AND SANITATION PLANNING AND MANAGEMENT

Attribute Description: Equitable involvement and empowerment of community members in planning and management are achieved by centering rural community priorities.

Local stakeholders are often best suited to understand the effects of climate change on their communities as well as opportunities for adaptation. This is because of their close connection to the social and physical environments in their region along with a deep understanding of socioeconomic vulnerabilities and water insecurity issues (Dickson, Schuster-Wallace, and Newton 2016; McNeeley and Lazrus 2014; WaterAid 2021). Having a deep knowledge of their existing assets and strengths, rural community members are uniquely positioned to identify opportunities for resilience (Taylor et al. 2024). It is important, for example, to center Indigenous leadership and knowledges in climate-resilient water and sanitation initiatives so that approaches uphold Tribal water rights and achieve water justice (Status of Tribes and Climate Change Working Group 2025). Water and sanitation planning and management will be best positioned to equitably advance climate resilience when centered around rural community priorities and perspectives. This section outlines strategies to elevate rural voices and values in climate, water, and sanitation plans and programs.

Beginning with a visioning stage before developing plans and programs

is one strategy to center rural community members in climate and water planning and management. For example, Michigan State University and Michigan Department of Health and Human Services developed the [Climate and Health Adaptation Planning Guide for Michigan Communities](#) with a special focus on climate planning in the rural context (Michigan State University and Michigan Department of Health and Human Services 2020). They include a case study of climate and health planning in the most rural county in Michigan — Marquette County. The project brought together stakeholders from 30 local governments and agencies (see [Section 7.5](#)). Before developing a plan, they held meetings to engage the community in a process to explore community values and concerns. They used visualizations as a key strategy to gather and synthesize local priorities into the planning effort (see Figure 13). The visualizations incorporated posters, maps, and other displays that improved engagement by illustrating how climate change harms public health and possible adaptations to promote resilience. This approach can help overcome the barrier of top-down decision making that is common in climate adaptation planning, which can be the result of uneven power dynamics and structures that exclude local culture, voices, and agency (Fernandez-Bou et al. 2021; Gonzalez 2017; McNeeley 2012; McNeeley and Lazrus 2014).

Beginning with a visioning stage before developing plans and programs is one strategy to center rural community members in climate and water planning and management.

FIGURE 13. Word Cloud of Community Priorities from Community Visioning Workshop

Source: (Michigan State University and Michigan Department of Health and Human Services 2020)

Another strategy to elevate rural voices in climate, water, and sanitation planning and management is to **utilize support and resources from community-based organizations and similar groups**. The Livelihood Knowledge Exchange Network's (LiKEN) [Community Engagement Guide](#) is a tool from a regional community-based organization to support rural community engagement in climate resilience water and sanitation. This resource offers practical tips for organizing community groups, running effective meetings, ensuring safety during fieldwork, and asking the right questions to improve water and wastewater systems, especially amid extreme weather challenges. By emphasizing local knowledge and inclusive decision making, the guide enables rural communities to advocate for fair and equitable solutions that address their unique needs and support resilience (Livelihoods Knowledge Exchange Network 2024a).

Rural voices can also be centered in planning and management by **fostering collaborations between communities and research institutions through boundary organizations**²² like the Community Partnerships for Self-Reliance (CPS). CPS is a partnership between the Alaska Native Science Commission, the University of Alaska Fairbanks, and rural Alaska communities. CPS helped four rural Indigenous communities (Igiugig, Koyukuk, Newtok, and Nikolai) develop community-driven climate adaptation plans focused on goals such as flood risk assessment and water rights (Chapin et al. 2016). By connecting local visions of self-reliance with technical expertise, CPS influenced broader planning decisions and expanded adaptation options tailored to local conditions and cultures. Partnerships with boundary or community-based organizations can be a powerful way to bridge government or utility climate, water, and sanitation planning and management and rural frontline communities' values, needs, and concerns.

22 Boundary organizations are structured intermediaries that bridge science with policy and practice to facilitate collaboration and knowledge exchange (Morse 2009). They can function outside of formal organizational structures, allowing for communication across non-traditional pathways and across different sectors and scales (Anderies, Janssen, and Ostrom 2004; Chapin et al. 2016; Guston 2001; Sternlieb et al. 2013).

Finally, **managers and planners can take proactive measures to encourage participation and offer compensation for participants** to provide accessible engagement opportunities and to value rural community members participation. Washington State Department of Commerce developed an [Environmental Justice Community Engagement Plan](#) that outlines strategies to reverse historical environmental injustices in the state (Washington State Department of Commerce 2022). Recognizing that it may be difficult for rural communities to participate in engagement activities, the plan recommends multiple strategies including:

1. holding meetings at locations where communities tend to gather;
2. offering travel reimbursement and lodging;
3. choosing locations with access to public transportation and ample parking; and
4. holding meetings virtually, if rural participants have access to internet and the virtual meeting platform.

The plan also recommends providing direct compensation for engagement, including gift cards, direct deposits, or checks. This can support individuals who may not be able to participate due to transportation costs, childcare costs, and lost wages for time off work.

LiKEN Community Care Coordinator, Madison Mooney, leads a Participatory Action Research session at a community meeting in Martin County, Kentucky.

Source: Photo by McKensi Johnson

Table 16 lists the four strategies for centering rural communities in water, sanitation, and climate planning presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.



TABLE 16. Strategies, Resources, and Case Examples for Centering Rural Communities in Climate, Water, and Sanitation Management and Planning

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Begin with a visioning stage to incorporate rural community insights into climate-resilient water and sanitation planning from the outset. 2. Utilize resources and support from community-based organizations to improve the representation of rural communities in climate adaptation and water and sanitation planning. 3. Foster collaborative research partnerships that provide a boundary function, connecting rural communities with regional and national planning efforts while developing locally tailored resources for self-reliance. 4. Take proactive measures to encourage participation, such as stipends, to empower rural community members to meaningfully engage in management and planning processes.	• Community Engagement Guide (Livelihoods Knowledge Exchange Network 2024a) (2) • Tribal Climate Adaptation Menu (Tribal Adaptation Menu Team 2019) (2) • Community-Driven Climate Resilience Planning: A Framework (Gonzalez 2017) (2)	• Marquette County community engagement in climate and health planning from Climate and Health Adaptation Planning Guide for Michigan Communities (Michigan State University and Michigan Department of Health and Human Services 2020) (1) • Community Partnerships for Self-Reliance support of rural Native Alaskan communities’ climate adaptation planning (Chapin et al. 2016) (3) • Verde Valley, Arizona Water Workshop (Randall 2024) (3) • Rural community listening activities in Water and Climate Equity in Rural Water Systems in the United States (Taylor et al. 2024) (3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

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

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

This attribute focuses on long-term, proactive planning strategies to help build rural utility and community financial stability in the face of climate change. As a result of utility and community financial stability, rural water and wastewater systems have a greater chance of keeping rates lower, helping to maintain more affordable utility bills for households (see [Section 8.5](#)). The two concepts of utility financial capability (understood as stability) and household affordability²³ 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 (River Network 2021).

Extreme weather, rising sea levels, and wildfires damage water infrastructure and increase the cost of water (Pacific Institute and DigDeep 2024). Small, financially strained utilities serving low-income populations are particularly impacted by these challenges (Teodoro and Thiele 2024). Population decline in some rural areas can decrease revenue from utility bill paying customers (River Network 2021; USDA 2025a). This decreased revenue can make maintaining financial health of rural utilities even harder. Climate change can also raise water treatment costs, disproportionately affecting small, rural systems (USDA 2017). These costs are often passed to ratepayers through higher water bills (Drugan 2023; River Network 2021). To address these challenges, this attribute presents strategies to support rural utilities to maintain financial stability and ensure affordable water and sanitation for communities in the face of climate change.

One way to help rural utilities and community systems stay financially stable amid climate change is to **integrate asset management into long-term planning that accounts for climate impacts on water and wastewater infrastructure**. Asset management is the strategic approach to overseeing capital assets, ensuring efficient budgeting for their operation, maintenance, and replacement while maintaining optimal service levels (Vedachalam, Male, and Broaddus 2020). Fredericktown, Missouri, a rural community serving just over 4,000 residents, used the [Climate Resilience Evaluation and Awareness Tool](#) (CREAT) to evaluate risks to their water infrastructure from extreme weather events like flooding

One way to help rural utilities and community systems stay financially stable amid climate change is to integrate asset management into long-term planning that accounts for climate impacts on water and wastewater infrastructure.

²³ 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 (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 (Davis and Teodoro 2014; Feinstein 2018; Pacific Institute and Community Water Center 2012; Teodoro 2018; Teodoro and Thiele 2024).

and drought. The assessment helped identify resilience strategies such as sediment removal and wastewater reclamation, which could reduce treatment costs by improving water quality (US EPA 2021b; 2016). Incorporating these strategies into long-term planning not only supports climate adaptation but can also strengthen the financial sustainability of rural systems by reducing future operational costs and infrastructure risks. CREAT can be used to assist water and wastewater utilities assess climate-related risks to utility assets and operations, allowing utilities to incorporate proactive measures to reduce risks into long-term planning, improving financial stability and health. The tool has five modules, including climate awareness, scenario development, consequences and assets, adaptation planning, and risk assessment. The tool is part of EPA's [Creating Resilient Water Utilities](#) (CWRU), which has additional resources like [Adaptation Case Studies for Water Utilities](#) (US EPA 2024b).

Additionally, rural utilities can conduct **demand forecasting to help ensure future water demand projections account for climate change, efficiency initiatives, and population changes**. 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). The Pueblo of Laguna Utility Authority in New Mexico used the Resilient Strategies Guide and CREAT to assess climate risks to its drinking water supply. With increasing drought threats, the assessment identified cost-effective resilience strategies, including water loss audits, a drought management plan, and water reuse (US EPA 2023b). While not a full demand forecast, these efforts support long-term planning — particularly if the expected water savings are factored into future projections. However, many small and rural utilities may face capacity and funding constraints that limit their ability to undertake such technical and data-intensive processes.

Finally, rural communities can **set rates proactively to prevent reactive rate increases that could render water and sanitation services unaffordable for rural communities**. For example, many small and rural water systems in California were unable to respond to drought impacts due to insufficient revenue from rates that remained stagnated for years, even decades (Klasic et al. 2022). This resulted in under-investment in infrastructure, which in some places failed during the 2012–2016 drought. The small water systems that adjusted their rate structures before the drought proved more resilient, as they were able to generate sufficient revenue to maintain infrastructure and take action in response to the changing conditions, thus reducing system failures (Klasic et al. 2022). This example demonstrates how proactive rate-setting can help rural water systems strengthen climate resilience, ensuring that they can maintain infrastructure and meet community water needs even in the face of climate challenges like drought.

Tools like CREAT and the Resilient Strategies Guide, as well others like the [Equitable Water Infrastructure Toolkit](#), can help small, rural, and economically-challenged utilities overcome barriers from limited expertise, resources, and capacity (Pacific Institute and Community Water Center 2012; River Network 2021).

Table 17 lists the three strategies for rural water and sanitation system financial health presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 17. Strategies, Resources, and Case Examples for Rural Water and Sanitation System Financial Health and Climate Resilience

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
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. 3. Employ proactive rate setting to prevent reactive rate increases that could render water and sanitation services unaffordable for rural communities.	• Climate Evaluation and Awareness Tool (CREAT) (US EPA n.d.-a) (+) • Resilient Strategies Guide for Water Utilities (US EPA n.d.-e) (+) • Equitable Water Infrastructure Toolkit (River Network 2021) (+) • Asset Management Guide for Small Drinking Water and Wastewater Systems (Rural Community Assistance Partnership 2024) (1) • The Basics of Financial Management for Small Community Utilities (Rural Community Assistance Partnership 2022) (1) • Asset Management: A Handbook for Small Water Systems (US EPA 2022a) (1) • Water Supply Forecasting (Natural Resources Conservation Service, n.d.) (2) • Rural and Small Systems Guidebook to Sustainable Utility Management (US EPA and USDA 2016) (3) • RCAP Rate Setting & Affordability Resources (Rural Community Assistance Partnership 2021b) (3) • Formulate Great Rates: The Guide to Conducting a Rate Study for a Small System (Rural Community Assistance Partnership 2021a) (3)	• Fredericktown, Missouri Prepares for Climate Change Drought Risk (US EPA 2016) (1) • Pueblo of Laguna Utility Authority Drinking Water Planning for Resilience with CREAT and Resilience Strategies Guide (US EPA 2023b) (+) • Adapting to extreme events: small drinking water system manager perspectives on the 2012-2016 California Drought (Klastic et al. 2022) (3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

7.4. RURAL 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 rural water and sanitation systems.

Preparing rural water systems for growing climate disruptions is essential to prevent catastrophic service outages and advancing equitable access to water and sanitation, particularly for underserved rural communities (Pacific Institute and DigDeep 2024; University of New Mexico Southwest Environmental Finance Center 2024). After Hurricane Helene made landfall in September 2024, it brought catastrophic winds and rainfall throughout six Southeastern states, resulting in deadly flooding. In North Carolina, the storm's impact on infrastructure was extensive, damaging 163 water and sewer systems (Governor Roy Cooper 2024). In Buncombe County, infrastructure failures disrupted water services for tens of thousands of residents (Verduzco, Amy, and Seewer 2024). Rural communities in North Carolina were disproportionately impacted, with 80% of disaster-declared areas in rural regions (Marshall et al. 2024). Many of these regions have higher rates of older adults, people with disabilities, or mobile home residents (Marshall et al. 2024).

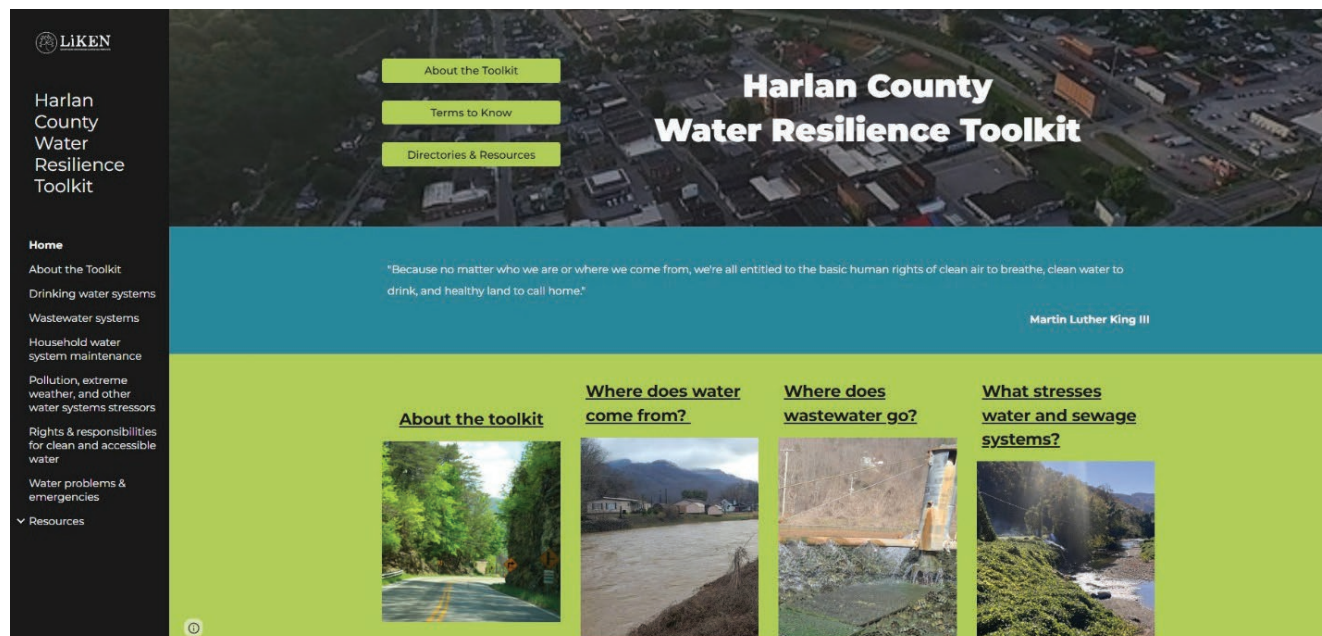
Climate disaster preparedness and response plans can support rural water and sanitation systems and by enhancing social networks and leveraging local knowledge to address inequitable risks (Taylor et al. 2024). Yet many small rural communities often have to focus on immediate issues and do not have the time or capacity to plan for climate disruptions to water and sanitation systems (Taylor et al. 2024). This attribute includes strategies for rural communities to prepare and recover from growing climate disasters and to support resilient water and sanitation systems.

A key strategy to support rural communities in preparing for climate disasters is to **develop emergency response plans that advance equitable access to water and sanitation services during disruptions**. While water systems serving more than 3,300 people are required under America's Water Infrastructure Act of 2018 to develop emergency response plans, small, rural systems are not required to have these plans. This can leave rural areas unprepared to cope with climate disruptions (Payton Scally et al. 2021; US EPA 2024d). The Rural Community Assistance Partnership (RCAP) has [multiple resources](#) for small and rural water and wastewater systems to prepare emergency response plans. This includes risk and resilience assessment worksheets, emergency response planning guide, and a video on preparing wastewater systems for disasters (Rural Community Assistance Partnership, n.d.-c). While not entirely focused on equity or climate disruptions, these actions bolster water resilience that, in turn, makes them more climate resilient. These resources, along with those in Table 18 below, can help rural and small water and sanitation systems plan for climate risks and overcome the common barriers, such as lacking the staff, tools, and expertise to manage emerging challenges (University of New Mexico Southwest Environmental Finance Center 2024).

In the [Water and Climate Equity in Rural Water Systems in the United States](#) project, technical assistance providers identified the need for educational tools for rural communities on climate disasters and their impacts on community water systems (Taylor et al. 2024). Rural water and wastewater systems and their supporters (e.g., nonprofits) can **develop and utilize local tools about**

climate disruptions to water and sanitation systems to inform residents, encourage participation in planning and management, and bolster community preparedness. An example of a rural community educational tool on climate impacts to water and wastewater systems is the [Harlan County Water Resilience Toolkit](#) (see Figure 14). The toolkit was designed to help the rural communities in eastern Kentucky better understand and prepare for climate stresses such as catastrophic flooding, drought, and extreme heat (Livelihoods Knowledge Exchange Network 2024c). The toolkit helps to inform residents and empower them to engage in climate-preparedness planning.

FIGURE 14. Snapshot of Harlan County Water Resilience Toolkit



Source: Livelihoods Knowledge Exchange Network 2024b

To help ensure equitable access to water and sanitation during and after disruptions, rural water and sanitation planners and managers can **include community input in risk assessments. This results in climate-preparedness plans and programs that address the needs of those most affected.** An example of this at the state level is the Colorado Basin Roundtables. Established in 2005 by the Colorado Water for the 21st Century Act, the roundtables facilitate discussions on water management and promote locally driven solutions. Representing each of the state's eight major river basins and the Denver metropolitan area, these roundtables engage a diverse range of stakeholders, bringing hundreds of citizens into Colorado's water decision-making process (Colorado Water Conservation Board, n.d.-a). The roundtables play an important role in balancing previously marginalized communities (e.g., West Slope rural communities) and sectors (e.g., nonconsumptive users such as recreation or ecosystem protection) in water management throughout Colorado.

For example, in the Southwest Basin Roundtable's [Basin Implementation Plan Volume 1](#) (BIP), a range of rural stakeholders were included in the planning process to address water supply and drought (Southwest Basins Roundtable 2022). The BIP brought together local leaders from across the region to assess risks and develop collaborative strategies to mitigate the impacts of climate change

on water sources. One key objective identified was to address drought impacts on agriculture, a vital driver of the region's economy. To tackle this challenge, the first volume of the BIP included a strategy to support measures that increase carryover storage²⁴ in Southwest Colorado reservoirs²⁵ (Southwest Basins Roundtable 2022).

Rural communities can participate in **training and workshops, especially focused on equity, to prepare water and sanitation systems for climate disruption**. For example, the Model Forest Policy Program, along with collaborators, developed the [Resilient Rural America Project](#). The project offers self-guided, no-cost training modules to build local capacity and resilience to climate disruptions for rural communities in the US (Resilient Rural America Project, n.d.). These are designed to support rural leaders and stakeholders in addressing resource gaps and enhancing resilience in natural resource protection, public health, and infrastructure. The modules provide streamlined processes for risk assessment, strategy development, and actionable steps for rural resilience to include in plans and programs, particularly in response to extreme weather and flood mitigation (NOAA 2022; Resilient Rural America Project, n.d.). While not explicitly focused on equity, the trainings include guidance on prioritizing adaptation actions that address high priority risks and opportunities with the goal of increasing local capacity to extreme weather. This, along with the additional trainings linked in Table 18 below, offers a good starting point for rural water and sanitation systems to begin the process of equitably preparing for climate disruptions.²⁶

RCAP, LiKEN, and the Pacific Institute are developing Tabletop Exercises to support rural communities equitably prepare for climate disasters and disruptions to water and sanitation. Tabletop Exercises are structured, interactive activities that allow key decision makers to practice responding to simulated water and climate emergencies under the guidance of a trained facilitator. These exercises help identify gaps in emergency response plans, highlight the most at-risk members in a community, improve decision making under pressure, and strengthen collaboration among participants.

Another strategy to prepare rural communities for climate disruptions is to **integrate a variety of water sources into programs and plans to improve redundancy²⁷ and resilience**. Fredericktown, Missouri, a rural community serving just over 4,000 residents, used the [Climate Resilience Evaluation and Assessment Tool](#) (CREAT) to enhance its preparedness for climate disasters (US EPA 2021b). The tool helped the utility identify risks from future droughts and extreme precipitation events, including its lack of backup water supplies. This led to the development of climate adaptation strategies such as a water conservation strategy and development of a water reclamation system. To increase redundancy, the community secured a contract to access water from a nearby lake as a secondary

24 "Carryover storage" refers to the practice of retaining water in reservoirs during wet years to be used in future dry years, helping to ensure a reliable water supply during periods of drought.

25 Approximately 80% of the water in Colorado is on the Western Slope, yet about 90% of the population in the state resides on the Eastern Slope (Colorado Water Conservation Board, n.d.-b). This creates a water management challenge, balancing rural and urban needs alongside environmental, recreational, and economic demands. Climate change further intensifies these challenges by exacerbating drought and straining limited water supplies (Colorado Water Conservation Board 2023).

26 We acknowledge that depending on the White House administration, trainings and activities funded through federal sources may be limited in their ability to address equity and climate change. Rural communities and water systems can address equitable climate disaster preparedness from a range of angles, like community resilience.

27 "Redundancy" in water systems refers to the deliberate inclusion of spare capacity to absorb disruptions, withstand extreme pressures, and manage sudden surges in demand (Pacific Institute 2021).

source and identified a long-term plan to dredge its primary water source to boost storage capacity during emergencies (Indiana University, n.d.; US EPA 2021b).

Table 18 lists the four strategies to equitably prepare rural water and sanitation systems for climate disasters presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 18. Strategies, Resources, and Case Examples to Prepare Rural Water and Sanitation Systems and Communities for Climate Disasters

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Create emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for rural communities.	• Security, Resiliency, and Emergency Response Planning resources (Rural Community Assistance Partnership, n.d.-c) (1)	• Harlan County Water Resilience Toolkit (Livelihoods Knowledge Exchange Network 2024c) (2)
2. Develop and utilize local tools on climate disruptions to rural water and sanitation systems to inform residents, encourage participation in planning, and bolster community preparedness.	• Emergency Response for Drinking Water and Wastewater Utilities (US EPA 2014a) (1)	• Colorado Basin Roundtables (Colorado Water Conservation Board, n.d.-a) (3)
3. Include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected.	• Climate Evaluation and Awareness Tool (CREAT) (US EPA n.d.-a) (1, 5) • Extreme weather training modules (Resilient Rural America Project, n.d.) (4)	• Rural Community Assistance Partnership (RCAP), LiKEN, and the Pacific Institute tabletop exercises for rural climate emergency preparedness (Pacific Institute, n.d.) (4)
4. Participate in training and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions.	• Tabletop Exercise Tool for Drinking Water and Wastewater Utilities (US EPA n.d.-f) (4)	• Fredericktown, Missouri Prepares for Climate Change Drought Risk (US EPA 2016) (5)
5. Incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for rural communities.		

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

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 in rural communities.

Water management and planning are connected to multiple sectors, including housing, energy, land use, agriculture, health, and transportation, among others. In a changing climate, these interconnections can heighten existing risks, compounding their effects. In 2024, for example, Hurricane Helene caused cascading effects on rural communities in North Carolina. These included power and water outages, disruption to communication systems, and lack of access to water and sanitation for households and hospitals (Governor Roy Cooper 2024). Larger utilities are often more equipped than smaller rural utilities to handle the impacts of major water and sanitation disruptions (University of New Mexico Southwest Environmental Finance Center 2024).

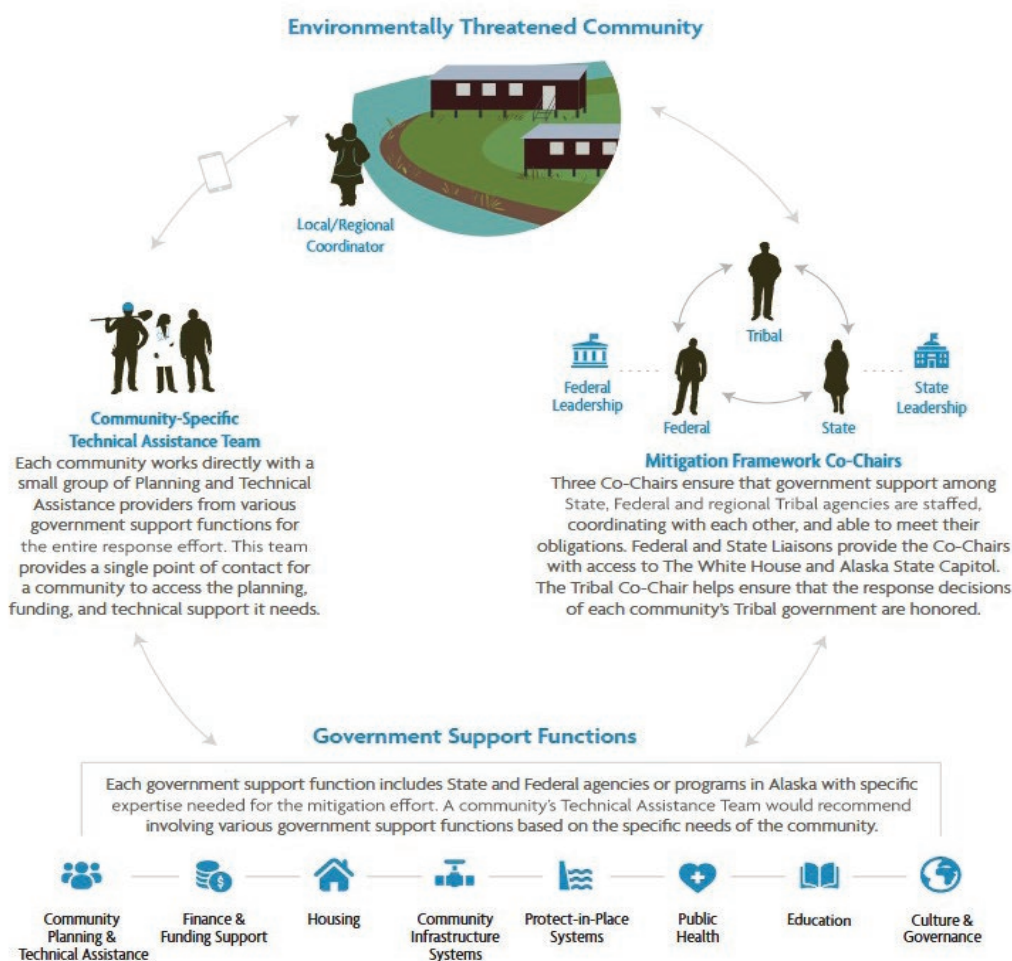
Water and sanitation management and planning require careful consideration of interconnected climate-related stressors. Effective planning considers how complex stressors impact multiple sectors and their influence on water and sanitation systems, especially in frontline communities (Clarke et al. 2018; Mach et al. 2023). This cross-sectoral coordination section includes strategies to support rural water and sanitation planners and managers in coordinating across sectors and scales of government to increase resilience to climate change. These strategies can help rural communities overcome barriers caused by historically siloed water planning and management practices. Siloing can hamper water and sanitation managers' ability to respond to climate risks, especially in rural communities with small and medium-sized utilities with limited staff, expertise, and information (Szalai et al. 2021; University of New Mexico Southwest Environmental Finance Center 2024).

One strategy for cross-sector coordination is to **align regional management and planning processes collaboratively**. An example of an integrated planning and management approach comes from California's [Integrated Regional Water Management](#) (IRWM) program. IRWM seeks to identify and implement regional water management solutions that enhance self-reliance, reduce conflict, and strengthen climate resilience while advancing social, environmental, and economic goals (California Department of Water Resources, n.d.-a). A regional success story comes from the Mojave's IRWM plan, which engaged stakeholders from different agencies and sectors (e.g., county governments, Tribal communities, industries, state agencies, etc.) to address key water management issues and challenges in the region (Mojave Water Agency 2014). One of the outcomes of the plan was the Mojave Water Agency [Small Water System Assistance Program](#). This program partners with the nonprofit California Rural Water Association to support disadvantaged and severely disadvantaged small water systems in the region (Mojave Water Agency, n.d.). It provides technical, managerial, and financial assistance to ensure long-term sustainability and compliance with water quality standards. This effort highlights how regional and collaborative planning can help identify and address the unique challenges faced by rural water systems, improving their resilience.

States, counties, and local water systems can **include interagency and cross-sector working groups in climate disaster response programs and plans**. This helps to clarify roles, establish coordinated technical assistance, and equitably integrate community input to support rural communities.

For example, the Alaska Native Tribal Health Consortium's (ANTHC) report, [The Unmet Needs of Environmentally Threatened Alaska Native Villages](#), outlines a robust, cross-sector, collaborative approach to improve the effectiveness and equity of federal and state support for small, rural Alaska communities facing climate change impacts (Alaska Native Tribal Health Consortium 2024). ANTHC proposed a conceptual Alaska Environmental Threat Mitigation Framework (Mitigation Framework). This was based on FEMA's National Disaster Recovery Framework, which is a coordinated management tool for disaster response at the state level (see Figure 15). The framework specifies the roles and responsibilities of various federal, state, Tribal, and regional departments and organizations across sectors, such as finance, public health, education, housing, and infrastructure. A key component of the proposed Mitigation Framework is the creation of community-specific technical assistance teams. These teams, made up of planners, agency representatives, and/or consultants, are responsible for facilitating communication between rural Alaska communities and multiple agencies and programs to connect communities with the support and resources available from a variety of sectors. This framework serves as a model for coordinated, cross-sector planning and management for climate disruptions in other rural communities.

FIGURE 15. Conceptual Alaska Environmental Threat Implementation Framework



Source: Alaska Native Tribal Health Consortium 2024

Rural water and sanitation systems and communities can also work together with nonprofit organizations to address complex and cross-sector challenges. In [Water and Climate Equity in Rural Water Systems in the United States](#), nonprofits LiKEN, RCAP, and the Pacific Institute developed the Water and Climate Resilience Framework (Taylor et al. 2024). The framework exemplifies collaborative action and learning by emphasizing the interconnectedness of community capacity, historical development pathways, and ecological pressures on rural water and sanitation systems. It recognizes that rural communities often possess valuable local knowledges, informal support networks, and cultural resources that are overlooked in traditional decision making. Using the Resilience Framework, LiKEN led listening projects in eastern Kentucky to examine and better understand complex local and cross-sector water and sewage systems challenges. Some of those challenges were historic disinvestment, the legacy of coal mining, and the resultant health impacts of failing water and sanitation infrastructure.

The team also engaged rural technical assistance providers (TAPs) and learned about resources needed to support rural water and sanitation. For example, TAPs expressed interest in resources that educate communities on climate disasters that affect local water systems and the need for tailored disaster preparedness training. Rural communities can strengthen their ability to equitably address climate change impacts by fostering partnerships between rural communities and nonprofits and co-designing strategies and resources to address cross-sector water and sanitation challenges.

Finally, rural water and sanitation managers and planners can **engage in specialized training to address climate impacts equitably and collaboratively across sectors.** The [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 2022e). The guide explains water interdependencies with six sectors: energy, food and agriculture, chemical, health care, emergency services, and transportation. It then outlines the steps for planning and conducting with representatives from across these sectors a workshop around a hypothetical disruption to the distribution of safe water and wastewater. Workshops like these can help rural water and wastewater utilities assess community-wide preparedness for climate disruptions that leads to more proactive and coordinated planning for climate resilience. Given the interdependencies of water and sanitation infrastructure with other sectors, such training is important for effective, collaborative, and equitable disaster preparedness and recovery (see [Section 7.4](#) on climate disaster preparedness).

Table 19 lists the four strategies for cross-sector rural climate, water, and sanitation planning and management presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 19. Strategies, Resources, and Case Examples for Rural Water and Sanitation Cross-Sector Planning and Management

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Align management and planning processes strategically, using integrated and collaborative frameworks. 2. Include interagency and cross-sector working groups in climate disaster response programs and plans to clarify roles, establish coordinated technical assistance programs for rural communities, and incorporate equitable community input into plans. 3. Integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together. 4. Participate in specialized training and exercises to learn how to address climate impacts on rural communities equitably and collaboratively across sectors.	• Climate and Health Adaptation Planning Guide for Michigan Communities (Michigan State University and Michigan Department of Health and Human Services 2020) (1, 2) • Community-Based Water Resiliency Guide (US EPA 2022e) (4) • Inclusion, Diversity, Equity, and Accessibility in Exercises: Considerations and Best Practices Guide* (FEMA 2023b) (4)	• Colorado Water Plan (Colorado Water Conservation Board 2023) (1, 2) • California Integrated Regional Water Management Program (California Department of Water Resources, n.d.-a) (1, 2) • Yakima River Basin Integrated Plan (Washington State Department of Ecology, n.d.) (1) • The Unmet Needs of Environmentally Threatened Alaska Native Villages (Alaska Native Tribal Health Consortium 2024) (2) • Water and Climate Equity in Rural Water Systems in the United States (Taylor et al. 2024) (3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

*As of January 2025, this guide is no longer available on FEMA's website. The link provided directs to an archived version of the resource.

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

Attribute Description: Water planners and managers continually monitor and evaluate plans and programs to support equitable and climate-resilient outcomes for rural communities.

Building climate resilience involves learning, adapting, and transforming, which requires monitoring and evaluation (M&E) to track progress and effectiveness (ARUP et al. 2019). M&E are important for understanding what initiatives work, for whom, and why, as well as identifying unintended consequences (Biagini et al. 2014; Spearman and McGray 2011; United Nations Children’s Fund and Global Water Partnership 2017; United Nations Development Program 2023). In climate, water, and sanitation planning, performance monitoring tracks progress, guides investments, and informs new strategies (WaterAid, Australian Aid, and Water for Women 2021). M&E can be an ongoing, collaborative process between planners, managers, and community members, where continuous feedback and reflections help assess effectiveness and equity, as well as inform adjustments for future planning. Yet, M&E of climate change adaptation measures are underdeveloped (Dupuits et al. 2024; United Nations Framework Convention on Climate Change, Kyoto Protocol, and Paris Agreement 2023; Wasley et al. 2023). This section discusses strategies for rural communities to incorporate M&E in their climate and water plans and programs to increase climate resilience.

To ensure M&E reflects rural communities’ values and needs, water and sanitation planners can **engage community members and organizations in designing and implementing inclusive, locally informed M&E frameworks**. For example, 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 the 1854 Treaty Authority features a comprehensive M&E framework. The goal was to investigate how climate change impacts the Tribes’ natural and cultural resources within the 1854 Ceded Territory²⁸ and to identify actions to create more climate resilience (Stults et al. 2016). The adaptation strategies identified in the plan were informed by both local knowledge and climate science. The plan includes multiple strategies to monitor and assess conditions for each key focus area (e.g., air quality, aquatic and terrestrial plants, culturally significant places). To address climate change impacts on water quality, for example, the plan includes actions to monitor fish mercury concentrations as guidance for food safety. Another example of M&E in the plan is developing an annual monitoring program of invasive plant and animal species and creating response strategies if wetland habitat begins to degrade.

The M&E actions above represent **equity-focused indicators to track climate resilience outcomes** because they focus on tracking culturally significant species or ecosystems identified by the communities most impacted by climate change. Another example of equity-focused indicators to track rural climate resilience comes from a study that used a framework to evaluate the resilience of Harlan County, Kentucky to flood hazards called “PEOPLES” (Population and demographics, Environment and ecosystem, Organized governmental services, Physical infrastructure, Lifestyle and community competence, Economic development, and Social-cultural capital) (Melendez and

²⁸ 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).

Gutierrez Soto 2024). The authors looked at multiple indicators for each category. For the population and demographic category, for example, indicators included population density, equity, population stability, place attachment, educational attainment equality, and homeownership. The study found that to increase resilience of the rural county to flood impacts, investment in transportation, evacuation, and recovery processes would be needed. While not solely focused on water and sanitation, this case study showcases the potential for the PEOPLES framework to evaluate the impact of strategies aimed at increasing the equity and climate resilience of rural systems. Rural communities can benefit from evaluating how risks change after implementing resilience-strengthening strategies. This helps to inform adjustments to existing climate disaster mitigation and response plans and programs.

Tools are available to support rural water and sanitation planners and managers to incorporate community input into M&E activities. The 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 (Great Lakes Integrated Sciences and Assessments, n.d.). For example, the toolkit recommends taking steps like changing the language used to communicate with stakeholders to meet the needs and preferences of diverse communities, selecting methods of analysis that reflect cultural values, and including traditional knowledge in M&E to better understand drivers and impacts of climate change.

To enhance the implementation and effectiveness of climate, water, and sanitation M&E, a key strategy is to **dedicate funding for M&E within climate adaptation planning budgets** (Olazabal et al. 2017). Embedding climate-resilient M&E into the budget from the start helps ensure sustained support and accountability throughout planning and implementation of climate adaptation projects. However, the most at-risk communities often face significant funding barriers and shortfalls for climate adaptation planning and implementation (Wasley et al. 2023). While including a budget item for M&E does not solve the funding challenge, it can help prioritize M&E as a critical component of climate adaptation efforts.

Finally, utilities act as anchor institutions by providing critical services and maintaining trusted relationships within their communities. **The incorporation of robust M&E in both new plans and existing operations and programs is beneficial for climate-resilient water and wastewater services.** Through these practices, utilities can focus on equity, trust-building, and accountability, all vital for addressing systemic inequities in rural water and sanitation access.

Table 20 lists the four strategies for M&E of rural climate, water, and sanitation planning shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 20. Strategies, Resources, and Case Examples for Rural Monitoring and Evaluation of Climate, Water, and Sanitation Plans and Programs

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Involve community members and community-based organizations in the design and implementation of monitoring frameworks to promote inclusive, attainable, and locally informed processes.	• Adaptation Monitoring and Evaluation Toolkit (Great Lakes Integrated Sciences and Assessments, n.d.) (1) • Monitoring and Evaluation for Climate Resilient WASH (United Nations Children’s Fund and Global Water Partnership 2017) (2, 4) • Climate Adaptation Monitoring, Evaluation, and Efficacy Testing Dashboard (Climate Adaptation Knowledge Exchange, n.d.) (+)	• Climate Change Vulnerability Assessment and Adaptation Plan (Stults et al. 2016) (1, 2)
2. Use equity-focused indicators to effectively track climate resilience outcomes of water and sanitation plans and programs across rural communities.		• Harlan County, Kentucky flood resilience PEOPLES framework (Melendez and Gutierrez Soto 2024) (2)
3. Allocate specific funding for monitoring and evaluation (M&E) in climate adaption planning efforts so that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives.		
4. Apply M&E to both new initiatives and existing practices to comprehensively address systemic inequities and enhance accountability.		

7.7. MANAGEMENT AND PLANNING SUMMARY

The management and planning strategies outlined in this section are important for enhancing the climate resilience of rural communities. Protecting the source water for rural water systems is critical. These communities face challenges to access drinking water and sanitation that are now exacerbated by climate change. Actively engaging rural communities helps to ensure that their needs, cultures, and priorities are centered in planning processes and management efforts. Rural 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 essential. Incorporating community input helps to identify vulnerabilities and design adaptive strategies tailored to rural community needs. Cross-sector coordination can help bridge silos and foster collaboration among stakeholders. This enhances the effectiveness and climate-resilient outcomes of rural water and sanitation plans and management 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 rural communities.



8. Funding and Financing

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

Equitable, climate-resilient water and sanitation for rural communities require significant funding to prepare for and recover from climate disruptions. One challenge to building and maintaining climate-resilient water and sanitation systems for rural communities is the inequitable distribution of and access to funding, financing, and insurance options (Wasley et al. 2023). Centralized rural water and wastewater systems face numerous barriers and challenges to accessing these resources, such as lack of sufficient local revenue base, unrealistic match and burdensome repayment requirements, and other capacity limitations (see [Section 10](#) on capacity building) (Frank 2022; Hansen et al. 2021; Hasert et al. 2024; Headwaters Economics 2021; K. Smith 2023; Status of Tribes and Climate Change Working Group 2021).

For many rural households where onsite, decentralized water and wastewater are the only viable options, costs often fall entirely on the homeowner for installation, maintenance, and repairs (Calabretta, Cunningham, and Vedachalam 2022; Gibson et al. 2020). This section describes five attributes of adequately funded rural water and sanitation. These are:

1. funding and financing for climate-resilient rural water and sanitation infrastructure;
2. climate-resilient operations and maintenance (O&M);
3. funding, financing, and disaster insurance for disaster preparation, response, and restoration;
4. funding and financing for alternative approaches to equitable, climate-resilient water and sanitation; and
5. affordable climate-resilient water and sanitation for rural households.

We review a variety of strategies and opportunities for rural communities to obtain adequate funding and financing for equitable, climate-resilient water and sanitation systems. This funding and financing section (and report as a whole) was primarily written in 2024, then in early 2025 federal programs, funding, and staffing experienced major changes. Some federal resources and funding mechanisms became either temporarily or permanently unavailable and their future

uncertain. These sudden changes and uncertainties create additional barriers for rural communities seeking to access many of the strategies presented in this report that rely on federal programs and funding. Wherever possible, non-federal examples were incorporated and where altered or canceled federal programs are referenced, archived versions of websites and documents have been provided, although additional resources may become unavailable after this report is published. For additional information and examples of funding and financing for equitable, climate-resilient water and sanitation, see the corresponding Section 8 in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).

8.1. FUNDING AND FINANCING FOR CAPITAL INVESTMENTS IN CLIMATE-RESILIENT RURAL WATER AND SANITATION INFRASTRUCTURE

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

Designing, constructing, and adapting climate-resilient water and sanitation infrastructure for rural communities and households require significant funding. Several sources can provide funding for climate resilience and adaptation of water and sanitation infrastructure, such as 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.

The Drinking Water State Revolving Fund (DWSRF) was established in 1996 to provide drinking water systems with financial assistance to meet the requirements of the Safe Drinking Water Act (SDWA). The Clean Water State Revolving Fund (CWSRF) was created in 1987 to provide financial assistance to help municipalities, local governments, and wastewater utilities comply with the Clean Water Act (CWA). 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. State revolving funds (SRFs) are operated by states primarily as low-interest loan funds for capital projects (US EPA 2023d; US EPA 2023e).²⁹ As these loans are repaid, the funds go back into the state's SRF "pots," helping to maintain funding for future projects. One approach to **getting more of the funding from the SRFs to rural communities is to prioritize these funds for equity needs**. However, the Brookings Institute found that most 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). As of 2025, changing priorities at the federal level may encourage states and other funding agencies (such as nonprofits and corporations) to further remove existing references to environmental justice, equity, or other references that help prioritize funding for equity needs (The White House 2025).

²⁹ The forms of assistance from CWSRF and DWSRFs include below-market rate interest, no interest, and negative interest loans; purchase of debt or refinancing; guarantees or insurance for improving credit, guaranteeing SRF revenue debt, providing loan guarantees, and other forms of subsidization.

Ensuring sufficient funding requires **addressing the inequitable distribution and access to funding and financing** that have historically hindered rural communities from pursuing climate change adaptation (Wasley et al. 2023). While federal funding opportunities are available, they can be difficult for rural communities to access.³⁰ For instance, match requirements can place disproportionate burdens on rural communities with smaller populations to raise matching funds (K. Smith 2023). Funding eligibility requirements can block small systems with poor financial records and low operating budgets from accessing funds (Vedachalam, Male, and Broaddus 2020). DWSRFs can also be difficult for small and rural systems to access because smaller systems tend to have low financial capacity, meaning they lack sufficient operating reserves, revenue options, and financial expertise. This makes it challenging to access loans, which are a primary form of financial assistance from SRFs (Greer 2020; Scanlan and Husain 2022). Other barriers to accessing SRFs and federal funding include lack of staff expertise, institutional support, and sufficient time to apply for opportunities (Biagini et al. 2014; Glade and Ray 2022; Headwaters Economics 2024; Taylor et al. 2024).

The 2021 Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL), provided funding for equitable and climate-resilient water and sanitation projects in rural communities. In rural Colusa, California, drought intensified by climate change has made water supplies unreliable. The community is designated as “disadvantaged” by the state of California and received \$3.3 million from BIL to install water meters, replace old and asbestos cement pipes, install fire hydrants, and properly eliminate access to two contaminated wells, among other activities to protect drinking water supplies and improve conservation (US EPA 2024f).

State-level funding and financing programs are increasingly important for supporting rural communities.

The Alaska Native Angoon Community Association in southeast Alaska received approximately \$1.6 million in BIL funding in 2022 through the Indian Health Service Division of Sanitation Facilities Construction Projects program to replace a well and rehabilitate its intake structure to allow the water pumps to adjust to low rainfall and changing lake conditions caused by climate change (Indian Health Service 2024).

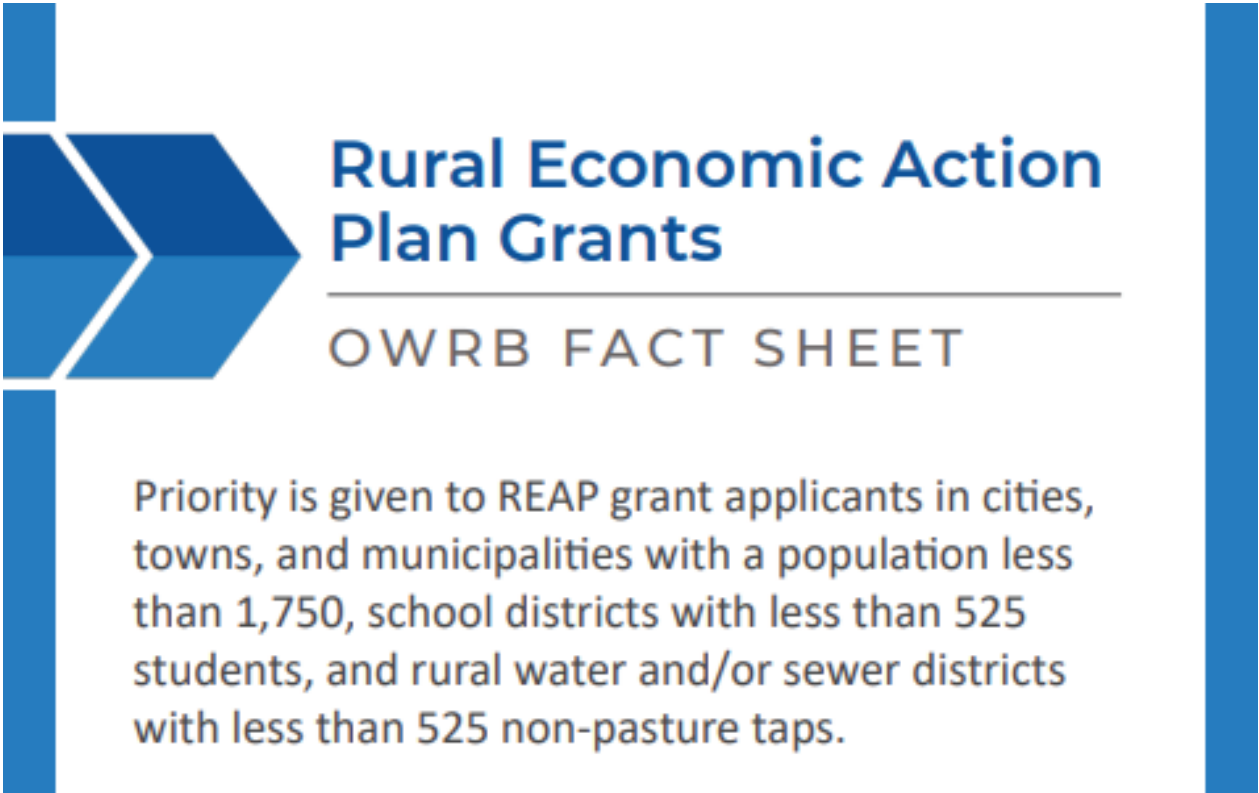
Rural households that are unable to connect to centralized water or wastewater systems need access to **funding or financing to help them construct climate-resilient onsite systems, like wells and septic tanks**. The regional nonprofit Southeast Rural Community Assistance Partnership operated a Certified 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). More work is needed to understand the effectiveness and extent of the need for this type of funding strategy in rural areas.

State-level funding and financing programs are increasingly important for supporting rural communities. In Oklahoma, the Oklahoma Water Resource Board offers the Rural Economic Action Plan grant program to help rural water and sewer districts upgrade and repair infrastructure (see

³⁰ With the new White House administration starting January 20th, 2025, the future of these federal funding sources is uncertain.

Figure 16). The grants are prioritized for cities, towns, and municipalities serving 1,750 people or fewer or rural water and/or sewer districts with less than 525 “nonpasture” customers (Oklahoma Water Resources Board, n.d.-a). In 2025, Wellston Public Works Authority received a \$79,427 grant from the Rural Economic Action Plan program to modernize their deteriorating infrastructure, improve reliability, and protect local water resources for the community (Oklahoma Water Resources Board 2025).

FIGURE 16. Portion of Rural Economic Action Plan Grant Program Fact Sheet



Source: Oklahoma Water Resources Board, n.d.-b

A report on state policies for small and rural water systems by the National Conference of State Legislatures offers other examples of state-level funding and financing programs for small and rural water and wastewater infrastructure (National Conference of State Legislatures 2022). However, many of the state programs identified by National Conference of State Legislatures and in this report do not directly address climate resilience.

Table 21 contains more relevant resources, tools, and rural case examples for funding and financing capital infrastructure in rural areas.

TABLE 21. Strategies, Resources, and Case Examples for Funding and Financing for Climate-Resilient Water and Sanitation Infrastructure in Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Increase the amount of funding available through federal and state programs, including the Clean Water State Revolving Fund and Drinking Water State Revolving Fund, that can be used to build and adapt climate-resilient rural water and sanitation infrastructure. 2. Ensure that funding and financing are accessible and do not have barriers for rural communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure. 3. Enact policies so that rural communities are receiving an equitable amount of benefits from climate and infrastructure funding. 4. Implement technical assistance programs to address barriers experienced by rural communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure. 5. Offer programs to help construct climate-resilient, onsite water and sanitation infrastructure and/or to connect rural homes and communities with decentralized infrastructure to more climate-robust centralized systems.	• Drinking Water State Revolving Loan Funds (US EPA 2023d) (1) • Clean Water State Revolving Loan Fund (US EPA 2024a) (1) • Colonias Infrastructure Fund (New Mexico) (New Mexico Finance Authority 2022) (1) • Flood Funding Finder by the American Flood Coalition (American Flood Coalition, n.d.) (2) • Tribal Community Resilience Program³¹ (Bureau of Indian Affairs, n.d.) (2) • Rural Water Infrastructure Committee in the Arizona Department of Environmental Quality (Arizona Department of Environmental Quality 2025) (2) • River Network's Equitable Water Infrastructure Toolkit (River Network 2021) (2, 4) • National Conference of State Legislatures (NCSL) report, State Policy Options for Small and Rural Systems (National Conference of State Legislatures 2022) (2, 3) • FloodWise Community Assistance program by Headwaters Economics (Headwaters Economics, n.d.) (4) • Community Development Program at Self-Help Enterprises (Self-Help Enterprises, n.d.) (4) • Southeast Rural Community Assistance Partnership's (SERCAP) Community Development Loan (SERCAP News 2022) (5)	• Many case examples under Massachusetts Vulnerability Preparedness (MVP) Action Grant (Massachusetts Executive Office of Energy and Environmental Affairs, n.d.) (1) • Many case examples under the Kentucky Waters Projects List (Kentucky Infrastructure Authority, n.d.) (1, 3) • Arizona Water Supply Development Revolving Fund (Water Infrastructure Finance Authority of Arizona, n.d.) (1, 3) • Funding Agency Coordinating Team hosted by Oklahoma Rural Water Association (Oklahoma Water Resources Board 2024) (2) • Livingston, Montana FloodWise Program (Headwaters Economics 2023) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

31 Formerly known as the Tribal Climate Resilience Program.

8.2. FUNDING AND ASSISTANCE FOR CLIMATE-RESILIENT OPERATIONS AND MAINTENANCE

Attribute Description: Climate-resilient operations and maintenance for water and sanitation systems in rural communities has adequate and sustainable funding and assistance.

Operations and maintenance (O&M) are two of the many utility functions that will be affected by climate change. Water operators and managers identified climate change as a driver of increased maintenance needs, operational disruptions due to electrical supply issues, and impacts on emergency operating conditions (Lyle, VanBriesen, and Samaras 2023). 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).

In this report, “O&M” refers to ongoing activities required to run and maintain water and sanitation systems, as well as routine checks, repairs, and adjustments of equipment while monitoring system performance to optimize efficiency and reliability. Climate-resilient O&M includes activities that bolster water or wastewater systems’ climate resilience. This can include standard O&M practices as well as additional measures specifically designed to address the impacts of climate change on infrastructure (see [Section 4.4](#) above for strategies related to equitable, climate-resilient O&M). Funding water and wastewater system climate-resilient O&M in the rural context is an understudied topic. However, it can be assumed that the barriers and challenges are similar to what rural communities face when trying to access funding for building or adapting climate-resilient infrastructure (discussed above in [Section 8.1](#)).

Research on barriers to funding water or wastewater system O&M in rural communities has primarily focused on the challenge of insufficient revenue caused by a limited customer base (Feinstein et al. 2020; Greer 2020). Additionally, most small water and wastewater 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). Systems that have operators close to retirement age are especially at risk from a smaller workforce pool in rural communities. One of the main barriers to climate-resilient O&M is the dearth of funding options. Despite the critical nature of O&M to ensuring equitable, climate-resilient water and sanitation, these activities are rarely eligible for government and private funding and financing (EBP and American Society of Civil Engineers 2021; US Government Accountability Office 2016). Furthermore, rural households with onsite water and sanitation systems are responsible for the O&M costs for their systems. This section describes strategies for funding and assistance for O&M to improve rural water and sanitation system’s resilience to climate change.

Water operators and managers identified climate change as a driver of increased maintenance needs, operational disruptions due to electrical supply issues, and impacts on emergency operating conditions.

In a small number of states, there are **grant programs that fund O&M for water and sanitation systems**. While no examples of grant programs that explicitly address water and sanitation system O&M for climate resilience were identified, there are examples of state funding programs that support O&M for small, rural water and sanitation systems.

The Kentucky Infrastructure Authority administers a state fund and process for providing O&M support to “troubled or economically restrained” public water and wastewater systems (Kentucky Infrastructure Authority, n.d.).³² The fund is called the Kentucky Water and Wastewater Assistance for Troubled or Economically Restrained Systems Fund, supporting capital and non-capital (such as O&M) projects that directly help water and wastewater systems avoid service disruptions or return to service after a statewide or local emergency has been declared. Like California’s, this fund is not explicitly for rural water or wastewater systems nor climate resilience, but it is directly targeted at supporting O&M related to service disruptions and natural disasters.

Another strategy that can help rural water and wastewater systems perform O&M to bolster climate resilience is by **working with technical assistance (TA) providers with climate knowledge and expertise**, which may provide financial relief for water and wastewater systems in rural communities. However, many TA providers lack sufficient funding to address climate resilience in their support efforts (Taylor et al. 2024). Still, several NGO and government-supported TA providers in the US focus their services on rural and small, underresourced communities. Three of the largest TA providers include the USDA’s Circuit Rider Program (through the National Rural Water Association), the Rural Community Assistance Partnership (RCAP), and the EPA’s Environmental Finance Centers (Rural Community Assistance Partnership, n.d.-a; USDA n.d.-a; US EPA 2024c).³³ The USDA’s Circuit Rider Program operates throughout the US and sends technical experts at no cost to work onsite with rural water and wastewater systems to help detect leaks, address water main breaks, develop asset management plans, and perform other tasks (see Figure 17) (National Rural Water Association 2025). RCAP is a national network of nonprofit organizations that provide technical assistance for water and wastewater systems and other support to rural communities in all 50 states. The Environmental Finance Centers are 29 academic institutions and other nongovernmental organizations across the country that provide technical assistance to water and wastewater systems to find and apply for funding.

³² In Kentucky, a public water or wastewater system can be designated as troubled or economically restrained based on a list of criteria related to median household income, water rates, or other metrics related to the financial health of the water or wastewater system (Kentucky Infrastructure Authority 2024).

³³ With the new White House administration starting January 20, 2025, the future of these TA programs is uncertain.

FIGURE 17. Portion of Circuit Rider Program Flyer

Circuit Rider Program Technical Assistance for Rural Water Systems

What does this program do?

This program provides technical assistance to rural water systems that are experiencing day-to-day operational, financial or managerial issues. Rural water system officials may request assistance from the Rural Utilities Service, or Rural Utilities Service staff may request assistance on behalf of the system.

Who are the Circuit Riders?

- Rural Utilities Service has consultants contracted with the [National Rural Water Association](#) who are experienced in managing issues that may arise in the day-to-day operations of rural water systems.
- [NRWA State Affiliates](#) provide the technical assistance in their states.

Source: US Department of Agriculture 2019

Rural residents with private wells and onsite wastewater systems have few options for climate-resilient O&M support, but some regions, states, counties, and other NGOs **offer programs that provide grants or assistance for income-qualified households to test well water, repair wells or septic systems, or train onsite system owners on O&M.** For example, Wake County in North Carolina offered a two-year Well & Septic Pilot Assistance Fund (Wake County North Carolina, n.d.). Eligible homeowners could receive grants to get their well or septic system repaired or to have their well water tested. An example of a similar effort that reaches a broader geography, RCAP offers no-cost training and assistance to households with wells and septic systems to ensure their systems are functioning properly. For private well owners, RCAP provides 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 also offers **free workshops, webinars, self-paced e-learning, podcasts, brochures, and a hotline for households with onsite systems to learn about the O&M of their systems.** RCAP and the Illinois State Water Survey at the University of Illinois Urbana-Champaign also maintain [privatewellclass.org](#), [wateroperator.org](#), and [decentralizedwastewater.org](#), which exist to provide free resource libraries and training opportunities for well and septic operators and owners.

Other places to look for support for O&M of wells and septic systems include 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). While few of these resources address O&M to improve climate resilience explicitly, regular maintenance activities can help contribute to the reliability of onsite systems during extreme climate events.

Table 22 shows additional resources, tools, and case examples relevant to O&M funding or technical assistance for rural water and wastewater utilities and onsite water and sanitation systems.

TABLE 22. Strategies, Resources, and Case Examples for Funding and Assistance for Climate-Resilient Water and Sanitation Operations and Maintenance

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Create and fund grant programs that explicitly name climate resilience and operations and maintenance (O&M) as funding priorities for water and sanitation systems. 2. Work with free technical assistance (TA) providers with climate knowledge and expertise to reduce the financial burden of O&M. 3. Offer programs that provide grants or assistance for income-qualified households to test well water, repair wells or septic systems, or train onsite system owners on O&M. 4. Provide free training and other resources that inform owners on well and septic system O&M to enhance climate resilience.	- California's Safe and Affordable Drinking Water Fund (California State Water Resources Control Board, n.d.) (1) Kentucky Water and Wastewater Assistance for Troubled or Economic Restrained Systems Fund (Kentucky Infrastructure Authority, n.d.) (1) Circuit Rider Program (USDA n.d.-a) (2) Rural Community Assistance Partnership (Rural Community Assistance Partnership, n.d.-a) (2, 3) USDA Rural Development Program's Single Family Housing Repair Loan and Grants program (USDA 2023b) (3) Decentralizedwastewater.org (University of Illinois at Urbana-Champaign, n.d.-a) (4) WaterOperator.org (University of Illinois at Urbana-Champaign, n.d.-c) (4) PrivateWellClass.org (University of Illinois at Urbana-Champaign, n.d.-b) (4)	Rio Bravo-Greeley School Water Treatment O&M Project (California State Water Resources Control Board 2024a p.33) (1) Wake County Well & Septic Financial Assistance Pilot Program (WaterNow Alliance, n.d.-c) (3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

8.3. FUNDING, FINANCING, AND DISASTER INSURANCE FOR CLIMATE DISRUPTIONS

Attribute Description: Rural 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.

To prepare for and respond to a climate disaster, rural water and sanitation systems need funding and insurance for response actions and extra equipment. After a climate disaster, for example, a rural water system may have additional costs from staff working overtime hours to restore service, the need to purchase or rent construction equipment to remove debris or repair damage, and longer-term expenses for replacing unfixable infrastructure. Rural communities also need funding prior to climate disasters to prepare. 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. 2019; US EPA 2023f; US EPA 2024e).

Rural households with onsite water and sanitation also need funding and insurance to help them prepare for and respond to the impacts of flooding, wildfires, sea level rise, and other climate disasters.

Rural communities face a number of barriers and challenges when trying to access disaster insurance or preparation, response, and restoration funding (Rural Health Information Hub, n.d.-a; Taylor et al. 2024; Thomas et al. 2019). Federal funding opportunities have historically been available, however, they can be challenging for rural communities to access and many are uncertain under changing federal administrations (described in [Section 8.1](#)) (Alaska Native Tribal Health Consortium 2024; Rural Health Information Hub, n.d.-a). Some of the barriers for rural communities to access funding include onerous funding match requirements, competitive and/or complex applications, lack of TMF capacity, and benefit-costs requirements that do not fit rural communities' values or needs (Alaska Native Tribal Health Consortium 2024; K. Smith 2023; Vedachalam, Male, and Broaddus 2020).

The Alaska Native Tribal Health Consortium (ANTHC) has documented how federal funding for hazard mitigation does not routinely cover solutions best suited for small, rural Alaska Native communities. These include actions such as protect-in-place, managed retreat, or relocation of their communities (Alaska Native Tribal Health Consortium 2024). In 2024, ANTHC estimated that \$90–110 million would be needed over the next decade to protect infrastructure in Alaska Native communities from

climate change-related environmental threats (Alaska Native Tribal Health Consortium 2024). To fund climate hazard mitigation in Alaska, ANTHC recommended that the **federal government provide increased funding for protect-in-place, managed retreat, and relocation and consolidate funding sources to provide a single source** or dedicated funding to multiple agencies that collaborate to support projects from a shared priority list to fully cover these strategies.³⁴ This recommendation is relevant beyond Alaska in places such as Kentucky, where rural communities are also exploring these strategies to reduce exposure to climate risks like flooding (Gaffney and Cherry 2025).

Immediately after a climate disaster occurs, rural water and wastewater systems often need rapid support to help with costs for emergency response and repairs. A strategy for helping rural communities with emergency responses to climate disasters is to **dedicate funds for declared emergencies and to simplify and expedite the approval process so funds are delivered quickly**. Washington State’s CWSRF allocates a portion of its funds, known as a “set-aside,” to the Emergency Funding Program, which assists small communities (populations of 10,000 or less) in addressing wastewater or stormwater emergencies that pose an immediate and serious threat to public health, safety, or the environment, as identified by both the community and the state (Washington State Department of Ecology 2024). Applicants must provide proof of a local declaration of emergency, which helps to waive certain bidding requirements. The maximum annual funding per community is \$500,000, and the loans are for up to 10 years at 0% interest. The funds can be used for costs such as, for example:

- acquisition of land needed for project implementation,
- construction of domestic and industrial wastewater facilities,
- cultural resources review,
- engineering reports,
- equipment and tools,
- permits required for project implementation,
- side-sewer laterals, and
- pump stations (Washington State Department of Ecology 2024).

Assistance from FEMA is often a main source of recovery funding after a climate disaster. However, research suggests that aid from FEMA can exacerbate wealth inequality in the communities that receive it (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

34 The three programs that ANTHC 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 Climate (now 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 Climate Resilience Program received funds from the BIL and the Inflation Reduction Act (IRA), however Fiscal Year 2024 marked the final year of increased available funding made possible through these laws (Bureau of Indian Affairs 2024). The Emergency Watershed Program also received funding through the BIL and IRA, however, the future of this program is uncertain due to changes in funding policies of the new White House administration in 2025 (Office of Management and Budget 2025).

as well as for those with less initial wealth (Howell and Elliott 2019). The researchers stated that these effects are the result of job loss, forced relocation, or higher rents due to a reduced housing stock post-disaster. Low-income households and non-property owners must use personal savings (if they exist) to compensate for expenses. 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 community needs (Drakes et al. 2021; Howell and Elliott 2019). Complex application processes for receiving post-disaster aid disadvantage certain groups such as foreign-born and less educated households (Grube, Fike, and Storr 2018). **More efforts are needed to guarantee climate disaster response and recovery efforts do not exacerbate wealth inequality in rural areas.**

The USDA Emergency Community Water Assistance Grant program offered **loans or grants to rural water systems recovering from climate-related emergencies that have affected drinking water access** (USDA 2023a). This program was administered through local USDA rural development offices. To be eligible, the community had to have a median household income lower than state nonmetropolitan areas. These loans and grants could be used to repair breaks or leaks in distribution lines and address related maintenance necessary to replenish water supply. The funds were only available to rural areas with populations under 10,000 (including colonias), through local governments, federally recognized Tribes, and/or nonprofit organizations. The types of events that qualify as emergencies include droughts, floods, tornados, hurricanes, as well as some non-climate disasters like earthquakes. Applicants did not need a federal disaster declaration to be eligible but required 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 were available for the repair of source water intake systems or up to \$150,000 for distribution system repairs (Reynolds 2024).

Emergency funding is also critical to repair or replace damaged onsite wells or septic systems in rural areas after a major flood, wildfire, or other climate-related disaster.

Emergency funding is also critical to repair or replace damaged onsite wells or septic systems in rural areas after a major flood, wildfire, or other climate-related disaster. The USDA piloted an emergency fund in 24 states through Section 504 Home Repair Loans and Grants that was designated for rural homes in Presidentially Declared Disasters (with an end date of July 2025) (USDA 2023b). **These funds were designated for households in rural areas to repair damage caused by the disaster, including repairs to wells and septic systems.** The eligibility requirements were restrictive, only allowing applicants who met very low-income requirements, who were 62 years of age or older, who owned their home and could occupy it within 12 months, and who had damage related to a Presidentially Declared disaster on or after July 18, 2022 (USDA 2023b). The maximum loan amount was \$40,000 with a 20-year fixed interest rate of 1% and a maximum of \$15,000 for a grant. While no longer available, this type of fund demonstrates the type of program that supports equitable recovery for rural onsite water and sanitation systems.

For non-federally declared disasters, or to supplement support from the federal government, **informal groups and NGOs can provide resources and financial assistance to help rural households respond to and recover from climate disasters** (Mathias et al. 2022). For example, local chapters of the American Red Cross respond to thousands of 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 quality of 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).

Insurance can offer rural households another means of recovering from climate disasters. Small, rural water and wastewater systems may be under-insured or not insured at all against climate disasters (Zach 2016). One study showed how rural and Tribal communities, renters, and non-US-born households are more likely to lack flood insurance than predominantly White, urban homeowners and US-born households (A. Maldonado, Collins, and Grineski 2016), leaving these groups at a higher risk of exposure to economic losses from climate disasters (US Government Accountability Office 2013). Flood insurance is particularly challenging for rural homeowners to access in part because federal flood maps do not cover large portions of rural areas (FEMA Technical Mapping Advisory Council 2023; US Government Accountability Office 2013). The flood maps are a primary source for examining flood risk and promoting whether or not homeowners should buy flood insurance (Flavelle et al. 2020). In places where the local municipal government does not participate in FEMA's National Flood Insurance Program, households in that community are not eligible for federal flood insurance (Campbell-Ferrari et al. 2024; FEMA 2005; US Government Accountability Office 2013). More solutions are needed to provide adequate insurance to rural communities to help them recover their water and sanitation systems from climate disasters.

More solutions are needed to provide adequate insurance to rural communities to help them recover their water and sanitation systems from climate disasters.

Table 23 provides resources, tools, and rural case examples for funding and financing for rural water and wastewater climate-disaster preparedness, response, and restoration, and for disaster insurance.

TABLE 23. Strategies, Resources, and Case Examples for Funding Climate Disaster Preparedness, Response, and Restoration, and for Disaster Insurance for Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Increase funding available through federal community preparedness and climate hazard mitigation programs for protect-in-place, managed retreat, and relocation, and consolidate funding to improve access to these programs for rural communities. 2. Dedicate funds for declared emergencies in rural areas and simplify and expedite the approval process so funds are delivered quickly. 3. Prevent climate disaster response and recovery efforts from exacerbating or increasing 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. 5. Designate funds for rural households to repair damage caused by disasters, including for repairs to wells and septic systems. 6. Expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities.	• Emergency Watershed Protection program (Natural Resources Conservation Service 2025a) (1) • Hazard Mitigation Assistance Grants (FEMA 2025) (1) • Emergency Community Water Assistance Grant Program (USDA 2023a) (2) • Small Business Administration's Disaster Loan Program (US Government Accountability Office 2022) (2) • Community Development Block Grant Disaster Recovery funds (US Department of Housing and Urban Development, n.d.) (2) • Communities Unlimited Community Infrastructure Lending program (Communities Unlimited, n.d.) (4) • Single Family Housing Repairs Loans and Grants after Presidentially Declared Disasters (USDA 2023b) (5)	• Armoring the eroding riverbank in McGrath protects critical community infrastructure (Alaska Native Tribal Health Consortium 2024, p. 117) (1) • Emergency Community Water Assistance Grants provided the town of Gifford, IL (USDA 2014) (2) • Communities Unlimited emergency loan to Maple Creek Farms Sewer and Improvement District (Shore 2025) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

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

Attribute Description: Alternative approaches such as nature-based solutions (NBS), green infrastructure (GI), water efficiency, and water reuse have sustainable, adequate funding sources to support climate-resilient water and sanitation in rural 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 (see [Section 6](#) for more on NBS and GI strategies that support rural climate resilience) (Jay et al. 2023; International Water Association, n.d.; Vigerstol et al. 2023). Funding and financing for these approaches vary by the scale of the project, the location, whether it is on public or private property and whether the benefits derived from the project are created for the public or for private entities (including households).

Funding and financing for GI is often separate from NBS because GI is typically implemented by local municipal agencies or private property owners to address regulatory requirements related to stormwater management. NBS projects are commonly 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 helps 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.

Funding for water reuse depends on the scale, property type, and end use. Water reuse is the practice of reusing wastewater treated only to the degree necessary for the intended end use. It can help build climate resilience by reducing the need for new or additional water supplies in drought-prone areas or where surface water or groundwater sources are already over used. Rural households can reuse water such as with a greywater system that captures wastewater from a sink and applies it for use in a toilet. Rural community-scale reuse systems are operated and maintained by wastewater utilities or municipalities to treat wastewater and then reuse it for irrigation, industrial processes, or drinking.

Rural communities that want to build climate resilience using NBS, GI, water efficiency, or water reuse may need funding to support planning, implementation, and ongoing maintenance of these projects. There are several challenges related to funding and financing these alternative approaches that broadly apply across rural as well as urban communities.

First, the costs and benefits of these strategies are often not well known and, in some cases, harder to quantify relative to more traditional infrastructure approaches (Brill et al. 2023; Roy et al. 2008). Second, 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 for justice and equity (Bertana et al. 2022). Third, project costs for NBS and GI are highly specific to the project type, the scale of the intervention, and local context, and therefore are not readily transferrable between project sites (Raymond et al. 2017; Václavík et al. 2016). And finally, to fund and finance alternative strategies for water and climate resilience, financial institutions may need to develop new project management cycles, implementation protocols, and monitoring frameworks (Bennett and Ruef 2016; Diringer et al. 2019; Vigerstol et al. 2023).

Federal and state programs can provide funding for NBS projects that enhance climate resilience in rural communities.

A partnership between the National Fish and Wildlife Foundation and the National Oceanic and Atmospheric Administration (NOAA) with support from the Bezos Earth Fund, the Emergency Coastal Resilience Fund helps fund resilience projects for rural, coastal communities that have already been impacted by hurricanes, wildfires, and other climate disasters (National Wildlife Federation 2022). For example, the program funded the Yurok Tribe along the coast in northwestern California to create a plan to protect community homes and critical infrastructure from flooding by performing instream and riparian habitat rehabilitation and floodplain restoration (National Wildlife Federation 2022). This project was also focused on studying restoration techniques to benefit the local salmon and lamprey populations.

Wetland protection and restoration are NBS approaches that can shield rural water systems by reducing flooding and restore groundwater supplies by recharging water into aquifers.

In all 50 states federal funding is available for implementing these alternative approaches to rural climate resilience through the Sewer Overflow and Stormwater Reuse Municipal Grants Program (US EPA 2021d; US EPA 2024i). In 2022, 35% of the funds from this program were designated for projects in rural communities (defined by the EPA as a population of 10,000 or less) or financially distressed communities (as defined by each state) (US EPA 2022h). This policy helped to **ensure that funds were available specifically for rural communities to implement alternative approaches to build climate resilience**. Some of the alternative climate adaptation and resilience projects supported by the program include rainwater harvesting collection, storage, and distribution systems; green roofs; bioretention/bioswales; permeable pavement; creating or protecting wetlands; and watershed management activities.

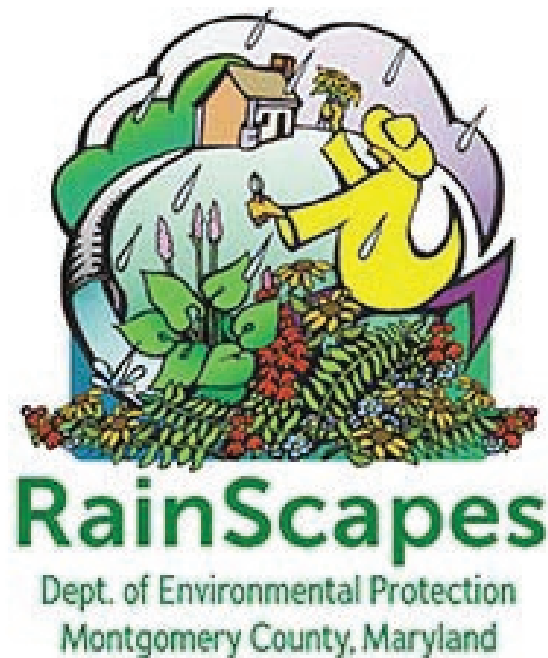
Wetland protection and restoration are NBS approaches that can shield rural water systems by reducing flooding and restore groundwater supplies by recharging water into aquifers (Vigerstol et al. 2023). The USDA’s Natural Resources Conservation Service’s (NRCS) Wetland Reserve Easement Program is designed to support landowners and Tribal communities in rural parts of the country in protecting and restoring wetlands that have been degraded from agricultural use (Natural Resources Conservation Service 2025b). The voluntary program operates by creating long-term or permanent

easements on agricultural lands that were previously wetlands, allowing NRCS to restore wetlands to support wildlife and other functions, like water retention and water quality enhancement. NRCS pays the landowner between 50% and 100% of the easement value and all costs and fees associated with recording the easement in local land records offices. For Tribes, NRCS offers a 30-year contract option and payment rates over the lifetime of the contract. In North Liberty, Indiana, NRCS worked with the Pokagon Band of Potawatomi Indians to restore 1,100 acres of wetlands, helping to improve water quality and flood retention, along with many other benefits for wildlife (Natural Resources Conservation Service 2025b).

In urban communities with centralized water and sanitation, households may have access to financial incentives from water utilities to replace inefficient fixtures and appliances or install greywater systems. This helps to support resilience to droughts and other water supply shortages for the urban household and community. Rural households that use onsite water and sanitation systems that lack a utility to support their efforts, however, may find other regional and local agencies to provide funding. This could be **county departments or resource conservation offices that offer similar types of financial support for alternative measures that can enhance rural climate resilience.** A water efficiency example is in Cochise County, Arizona where the county offers up to \$200 in rebates for installing high-efficiency toilets to county residents (outside of the largest city in the county) (Cochise County, n.d.).

An example of support for rural households to install GI features is in Montgomery County, Maryland where the Department of Environmental Protection offers a program called RainScapes (see Figure 18). The RainScapes program uses cost sharing to incentivize individual properties to install GI projects that reduce stormwater runoff from their homes (Montgomery County Department of Environmental Protection 2025). Adding GI projects like rain barrels, cisterns, permeable pavement, and rain gardens to properties helps to direct runoff away from homes, store it for later use, or recharges it into groundwater aquifers. This can help rural homeowners reduce the impacts of flooding on their home and can reduce the amount of stormwater traveling to centralized wastewater plants, which are increasingly overwhelmed by high-intensity rainfall events, increasingly common due to climate change. The program is only available to households outside of the municipal boundaries, making it more accessible to rural residents in the county. However, rebate programs and cost sharing can present a barrier for low-income customers who cannot afford to pay the full costs upfront before receiving monetary compensation, which can take several months (Clements et al. 2017; Pierce et al. 2021).

Adding green infrastructure projects like rain barrels, cisterns, permeable pavement, and rain gardens to properties helps to direct runoff away from homes, store it for later use, or recharges it into groundwater aquifers.

FIGURE 18. Montgomery County RainScapes Program

Source: *Montgomery Parks 2025*

Funding opportunities can also be created by nongovernmental organizations, including nonprofits and corporate entities, to support alternative, locally driven approaches to climate resilience for rural households. One example is the Water Is Life Fund, a program developed by DigDeep and Kohler Company to fund creative, high-impact solutions developed by local communities that provide access to water, sanitation, and hygiene to people in the US, US territories, and on sovereign Tribal Nations (DigDeep and Kohler Company, n.d.). The fund is not directly focused on building climate resilience yet creating water and sanitation access for those who do not currently have it is a foundational step toward resilience to climate disasters like drought, extreme heat, and wildfires. In the past the fund prioritized projects in rural communities, including the Navajo Nation, Central Appalachia, and the Texas colonias. Some examples of past funded projects include a pilot project of in-home water systems for regular water, a water delivery route in a high-need, water-scarce area, and a youth-led education and outreach effort to help promote the importance of safe water and distribute water filters to high-risk families.

Table 24 provides additional resources, tools, and rural case examples of funding opportunities for alternative approaches to equitable, climate-resilient water and sanitation.

TABLE 24. Strategies, Resources, and Case Examples for Advancing NBS, GI, Water Efficiency, and Water Reuse to Enhance Rural Water and Wastewater System Resilience

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
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.	• Emergency Coastal Resilience Fund (National Fish and Wildlife Foundation 2021) (1)	• Pokagon Band of Potawatomi Indians working with NRCS through the Wetland Reserve Easement Program (INNRCS 2019) (1)
2. Ensure that funding and financing for alternative approaches are accessible and do not have barriers for rural communities to identify, apply for, and use the assistance.	• Sewer Overflow and Stormwater Reuse Municipal Grant Program (US EPA 2024i) (1, 2) • NRCS Wetland Reserve Easement Program (Natural Resources Conservation Service 2025b) (1, 2)	• Verde River protection and restoration in Arizona with the Water Protection Fund (The Nature Conservancy, n.d.-a) (1)
3. Enact policies so that rural communities are receiving an equitable amount of benefits from funding for alternative approaches.	• The Trees Act (Oregon House Bill 3409) (3)	• Water Is Life Fund Previous Grantees (DigDeep and Kohler Company, n.d.) (4)
4. Offer programs to incentivize or pay for measures that enhance climate resilience of onsite water and sanitation in households in rural communities.	• Cochise Countyilet Rebate (Cochise County, n.d.) (4)	• Montgomery County, Maryland RainScapes Program (Montgomery County Department of Environmental Protection 2025) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

8.5. AFFORDABLE CLIMATE-RESILIENT WATER AND SANITATION FOR RURAL HOUSEHOLDS

Attribute description: Rural 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, especially for those served by the smallest, often rural, utilities (utilities with fewer than 10,000 connections) (Teodoro and Thiele 2024; US EPA 2024l). 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). Furthermore, climate change is contributing to rising costs for

small, rural water and wastewater utilities by driving water scarcity, degrading the quality of rural water supplies, and causing more frequent and intense storms that cause costly damage to water and wastewater infrastructure. Small, rural utilities are often unable to keep up with necessary maintenance and adaptation efforts of their systems (Pacific Institute and DigDeep 2024). And additional costs are passed on to their ratepayers or are absorbed by the systems as deferred maintenance and more frequent service disruptions.

In 2024 the EPA estimated that more than 9,500 small utilities (with less than 10,000 connections) were servicing communities where greater than 40% of households would qualify for income-based assistance (US EPA 2024l).³⁵ However, income-based customer assistance programs can be expensive to fund and require staff time and capacity to manage, creating barriers for some small, rural water and wastewater utilities.³⁶ To help rural households maintain access to water, states, counties, and/or nongovernmental organizations can **create customer assistance programs to help rural households afford their water and wastewater bills**. Across the country, a variety of charitable organizations, such as United Way, partner with counties, community action agencies, nonprofits, and local municipal governments to deliver and connect households with financial assistance for utilities and other needs. To find local assistance, households can call 211 or go to 211.org and be connected to their local support organization or agency (see Figure 19). As of this writing, no state had successfully established a statewide water or wastewater customer assistance program, but recent attempts were made by groups in New Jersey, Michigan, and California (NRDC and National Consumer Law Center 2022; Ransom 2025).

FIGURE 19. United Way 211.org Webpage



Source: United Way Worldwide, n.d

³⁵ “Households were defined as qualifying for assistance if their income was less than the greater of 60% of state MHI and 150% of the Federal Poverty guidelines” (US EPA 2024l).

³⁶ There are exceptions, and some rural water and wastewater utilities offer income-based customer assistance programs. For example, in California privately owned water and wastewater utilities are required by the state utility commission (that regulates private utilities) to offer customer assistance programs, providing recurring financial assistance for rural and nonrural households’ water and wastewater bills across the state (Environmental Finance Center at UNC Chapel Hill, Corona Environmental, and Abt Associates 2017).

Water leaks and inefficient fixtures can contribute to high water and wastewater bills for rural households. Government or utility programs that help rural households **update inefficient fixtures with high-efficiency models or find and fix water leaks can also help them save water and lower their water, wastewater, and energy bills** (if hot water is saved). In regions where climate change is contributing to drought and water scarcity, these measures can also help build climate resilience for the households and the water systems that serve them. The federal Weatherization Assistance Program, previously administered by the US Department of Energy, provided funding to states, territories, and Tribal governments to help low-income households reduce energy costs and improve household health and safety (US Department of Energy 2023). Households participating in the program received repairs and replacements for water heaters, insulation for both water heaters and pipes, repairs and replacements to heating and cooling systems (some of which use water), replacement of inefficient showerheads, and other energy-saving improvements. An analysis of the program's impact in 2010 found that participating households received a water savings benefit of \$186 per year each (Tonn et al. 2015). Due to federal funding cuts in 2025, the future of the Weatherization Assistance Program is uncertain, however, it provides a model that states or other organizations could adopt to help rural households address water affordability and climate resilience challenges.

Government or utility programs that help rural households update inefficient fixtures with high-efficiency models or find and fix leaks can also help them save water and lower their water, wastewater, and energy bills.

The federal government **can reinstate federal assistance to help rural households that are unable to afford their utility bills**. From 2021 to 2024 the US Department of Health and Human Services ran the Low Income Household Water Assistance Program (LIHWAP), an emergency program to help low-income households nationwide get water service restored and prevent disconnections (US Department of Health and Human Services 2025). The program was distributed by states and supported urban, rural, and Tribal low-income households. However, the distribution of support was not always equitable, and in some states rural communities were less able to access the program (US Department of Health and Human Services 2025). For example, Illinois initially set a rule that LIHWAP support would be prioritized for households with \$250 or more in arrears (past due) from water or wastewater utility bills. The state found, however, that this effectively excluded many rural households that had substantially lower bills and arrears than urban households. In 2022, the state updated the policy so that there was no prioritization based on amount of arrears, which helped to reach more rural households. LIHWAP funds were also authorized to provide bottled water to households where access to public water systems was not available or where systems were facing water scarcity related to disasters; to pay vendors to fill water cisterns for households in remote, rural areas; and to support septic tank pumping at rural households not served by wastewater systems (US Department of Health and Human Services 2025). These specific authorizations helped LIHWAP funding to support water and wastewater affordability in rural areas, even where households were not connected to a water or wastewater utility.

Another way that states are ensuring water access for rural 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 — rural parts of the state included — from losing water access during extreme heat (Washington State Legislature 2023). This law is 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.

As described in earlier sections, rural 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. Grant, loan, and technical assistance programs for households with onsite systems are discussed in these sections.

Table 25 provides more resources and rural case examples that support affordable, climate-resilient water and sanitation access for rural communities.

TABLE 25. Strategies, Resources, and Case Examples to Help Rural Households Afford Water and Wastewater

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Create and offer utility customers assistance programs and other affordability interventions like leak detection and repair for income-qualified households.	• Calling 211 or using 211.org to find local assistance providers (United Way Worldwide, n.d.) (1)	• Many case studies of the Weatherization Assistance Program found in this report by Oak Ridge National Laboratory (Tonn, Rose, and Hawkins 2014) (4)
2. Reinstate and fund federal water and wastewater assistance programs so that customers of all water and wastewater utilities have access to financial assistance for paying their utility bills.	• Washington State Engrossed Substitute House Bill 1329, 2023 (Washington State Legislature 2023) (3)	• Grant recipient spotlights from the Administration for Children and Families highlights impacts of Low Income Household Water Assistance Program for rural and low-income households (Administration for Children and Families 2024) (2)
3. Enact laws at the state, local, or federal level that prevent water disconnections during extreme weather or climate events.	• State-funded Weatherization Assistance Program in Washington (Washington State Department of Commerce 2024) (4)	
4. Create and fund programs to help rural households find leaks and replace inefficient fixtures and appliances to help save on their water, wastewater, and energy bills and support climate resilience.		

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

8.6. FUNDING AND FINANCING SUMMARY

One of the main barriers to creating equitable, climate-resilient rural water and sanitation systems is inadequate and inaccessible funding. Rural water and sanitation systems need more financial support (e.g., grants and loans) that help them to build and adapt existing infrastructure, improve their ability to operate and maintain their systems, and rebuild and restore after climate emergencies. Rural communities that are dependent on onsite systems, such as wells and septic, also need funding and financing to help them afford costly upgrades and repairs to help protect them from droughts, floods, sea level rise, wildfires, and other climate disasters. This funding is needed to help reduce the cost burden of climate adaptation on rural communities and households, so that they can continue to afford to have running water and adequate sanitation in their homes.





9. Knowledge and Information

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

Achieving equitable, climate-resilient water and sanitation fundamentally requires transparent and accessible technical and community knowledges,³⁷ 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 rural 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 rural and Indigenous communities (Cash et al. 2003; Status of Tribes and Climate Change Working Group 2025). These include decision-support information and tools, communication tools, data acquisition efforts, digital databases, and remote communication technologies (Biagini et al. 2014).

Accessible and usable water and climate data serve multiple purposes: they enhance the ability of local governments to plan for and respond to climate disasters, support equitable distribution of resources, and help to ensure that the most vulnerable are not left behind. Accessible and usable data also empower rural communities 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 science- and evidence-based information. This is especially important in the context of climate change where conditions are rapidly evolving and the consequences of being unprepared can be catastrophic.

³⁷ 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 section highlights four attributes of water and climate knowledge and information for rural water and sanitation systems. These four attributes include:

1. usable water and climate data at appropriate scales;
2. inclusivity in the use of water and climate data, projections, and assessments;
3. incorporation of local and technical knowledges and ways of knowing; and
4. equitable data and information translation, communication, and dissemination.

We highlight strategies that are culturally appropriate and co-developed with rural communities. This includes case examples and online materials to help rural communities adapt the strategies to local needs and values (see the table at the end of each attribute for a compilation of resources). Not all strategies have corresponding case examples. For further details and additional case examples from other settings, refer to Section 9 of the [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).



Drought workshop at Wind River Reservation. Photo Credit: Shannon McNeeley.

9.1. USABLE WATER AND CLIMATE DATA AT APPROPRIATE SCALES FOR RURAL COMMUNITIES

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

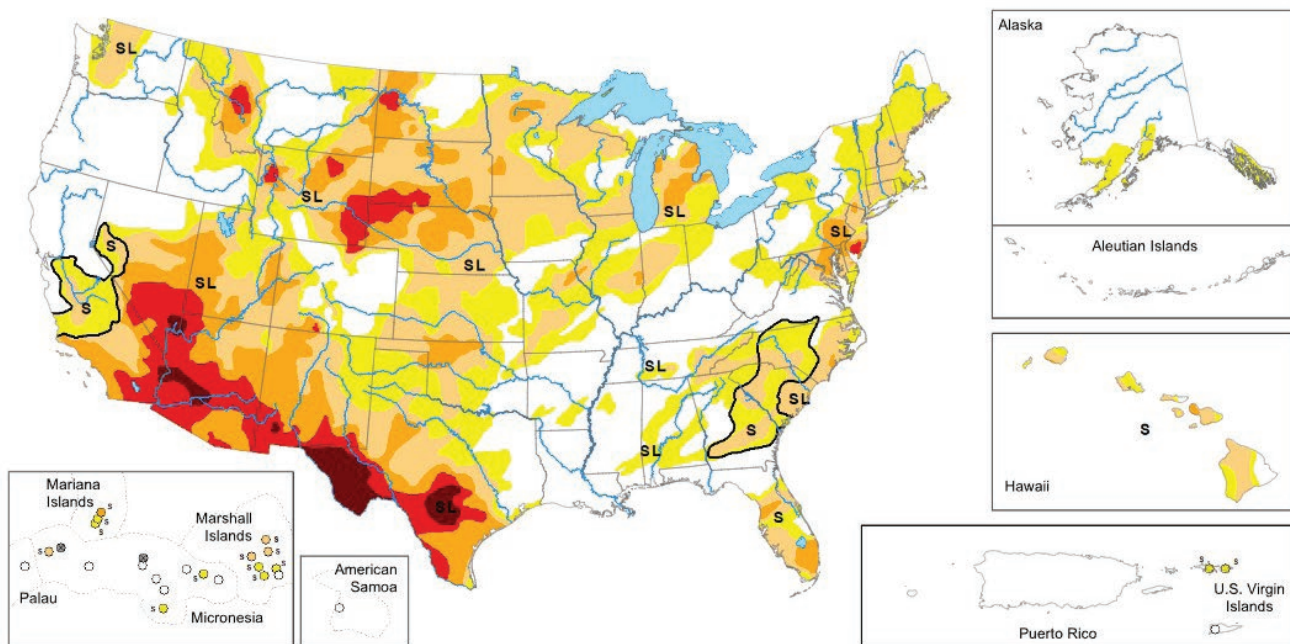
The accessibility and usability of water, climate, and related data at appropriate temporal and spatial scales is vital for effective rural water management and decision making. Data that aligns with the specific needs of water managers, utilities, and rural communities allows for more precise planning, timely responses to emerging issues, and informed policymaking.

Rural communities can 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 is used. The digital divide further exacerbates this issue, as some rural 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).

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.

One strategy to achieve usable water and climate data at appropriate scales for rural communities includes the use of resources like the [National Drought Mitigation Center's US Drought Monitor \(USDM\)](#), which provides **real-time, free, and easily understandable data** on drought conditions across the country (see Figure 20). The USDM's data is accessible at both broad and localized scales, allowing water managers and rural communities to make informed decisions about water usage, conservation measures, and emergency responses. Users can search the [National Drought Mitigation Center site by state](#), sector, or scale for a multitude of geographically specific data needs on variables such as [snow drought](#), [soil moisture](#), and [vegetation](#), among others.

The accessibility and usability of water, climate, and related data at appropriate temporal and spatial scales is vital for effective rural water management and decision making.

FIGURE 20. Example Map from US Drought Monitor**Map released: March 20, 2025****Data valid: March 18, 2025**☐ View grayscale version of the map

Note: More detailed regional maps, showing county level data, are available on the [USDM website](#).

Source: US Drought Monitor, n.d

Additional resources include predictive modeling tools, such as the [Arizona State University Colorado River Visualization Enterprise \(CuRVE\) Project](#) that allows users to analyze and communicate the effects of climate, hydrologic, and management scenarios on the Colorado River. This interactive tool allows stakeholders in Arizona to explore locally relevant datasets. CuRVE provides credible, unbiased research to support small community stakeholders — including rural and Tribal communities, individual community water systems, and agricultural districts — who depend on the Colorado River but may lack technical and policy expertise or rely on limited or complex data (Arizona State University, n.d.-d). By helping these stakeholders visualize and analyze different scenarios at the appropriate temporal and spatial scales, CuRVE bridges this knowledge gap and promotes sustainable, equitable water management in the face of climate change.

Another example is a partnership between Tribes, agency and academic scientists, and community members at the Wind River Reservation in Wyoming that **utilized a co-production of knowledge approach** to integrate technical data and information with local and Indigenous knowledges. The goal was to better prepare for 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 the capacity of the Tribal water managers to use technical drought decision-support information and tools such as the US Drought Monitor 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. Data and information were tailored to the reservation and at watershed scales that were important and meaningful to the Tribes. 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, co-produced a [Wind River Decision Dashboard](#) along with quarterly Wind River Reservation Drought and Climate Summaries. The quarterly summaries were appropriately scaled to the reservation and included community and instrumental observations. These were distributed broadly throughout the reservation and used by water managers, agricultural producers, and other community members.

The aim is to make complex topics engaging, understandable, easily accessible, and free.

Another notable initiative is the Climate Resilience Toolkit, developed 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 rural 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, tagged by hazard type and sector. The database has links to related case studies to learn how other utilities and towns are centering equity within climate resilience plans (US Climate Resilience Toolkit, n.d.-c).

Another useful resource that provides locally relevant resources is the [Rural Groundwater Resilience Toolkit](#) — a collection of interactive resources designed to engage, empower, and activate Arizona communities (Arizona State University, n.d.-b). This toolkit also **improves access to trusted support and expertise to increase capacity and overcome technical, legal, and policy barriers**. The aim is to make complex topics **engaging, understandable, easily accessible, and free**. A variety of online resources are available and include interactive maps, videos, blogs, webinars, and podcasts. It also includes the [Arizona Water Chatbox](#) where users can ask water and climate questions and get immediate detailed answers from AI. Residents, decision makers, and other leaders learn about local water challenges, including drought and other [climate change related topics](#); access resources on [funding, training, and other programs](#); and [explore stories, innovative approaches, and sustainable solutions](#) to water management. Other ways to increase knowledge and information and overcome barriers is through free, in-person and locally driven and tailored workshops, such as the [Rural Groundwater Resilience Workshops](#). These workshops help rural communities engage in neutral dialogue to explore challenges and solutions, provide information and data with hands-on guidance, and implement strategies for sustainable and equitable use of groundwater.

Table 26 lists the five strategies for usable water and climate data for rural communities shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 26. Strategies, Resources, and Case Examples for Usable Water and Climate Data for Rural Communities

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Focus water and climate research and information on community needs and values instead of those of outsiders. 2. Make sure 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. 5. Increase access to trusted support and expertise to increase capacity and overcome technical, legal, and policy barriers.	• US Drought Monitor (National Drought Mitigation Center, n.d.) (2, 3) • Coupled Model Intercomparison Project, Phase 6 Frequently Asked Questions: A resource for water managers (Water Utility Climate Alliance 2024) (2,3) • US Climate Resilience Toolkit (US Climate Resilience Toolkit, n.d.-b) (1, 2, 3) • Colorado River Visualization Enterprise Project (Arizona State University, n.d.-a) (+) • Rural Groundwater Resilience Toolkit (Arizona State University, n.d.-b) (+)	• Wind River Reservation partnership to co-develop usable climate and drought data (Climate Adaptation Science Centers, n.d.) (+) • Rural Groundwater Resilience Workshops (Arizona State University, n.d.-c) (3, 4, 5) • Harlan County Water Resilience Toolkit (Livelihoods Knowledge Exchange Network 2024c) (+)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

9.2. INCLUSIVITY IN THE USE OF CLIMATE DATA, PROJECTIONS, AND ASSESSMENTS

Attribute description: Climate data and projections are used with the inclusion of rural 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 2019a). The rural communities that are disproportionately affected by climate and water-related hazards have unique knowledge of

local conditions (Mitchell et al. 2016). For example, involving rural 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 planning and development initiatives consider their specific needs and vulnerabilities, fostering resilience and sustainability (see [Section 7.2](#) for strategies to help center rural communities in climate, water, and sanitation planning).

One way to achieve inclusivity is by using an **end-to-end co-production approach to include local experts³⁸ from rural communities in the design, research, and development of decision-support information and tools**. One example of this is the [Water and Climate Equity Project](#), a collaboration between the Pacific Institute, RCAP, and [LiKEN's Water Collaboratory](#). Rural communities in Central Appalachia are engaged through LiKEN's Community Engagement Coordinators (CECs). The CECs and researchers consulted with and interviewed local experts to include local knowledges and insights alongside technical research on climate change and water impacts to determine community needs and possible leverage points, aiming to build local capacity to prepare water and sanitation systems for climate change impacts. One outcome was a [Water Resilience Toolkit](#) for Harlan County, Kentucky, that includes information about climate disruptions to water and sanitation systems and resources for community preparedness. CECs are continually gathering feedback from the community on ways to improve the tool, especially after climate disasters like the July 2022 and February and April 2025 flooding events in eastern Kentucky (Anderson and McNeeley 2025; Schreiner and Hall 2025).



CityWalk creek clean up event in Martin County, Kentucky. Photo Credit: Mountain Citizens.

³⁸ Local experts refer to individuals with a strong connection to and knowledge about their community. They can have a range of expertise from general local conditions to concerns about a specific issue to local culture and values.

Citizen science is one inclusive practice through which communities can be included in water and sanitation data gathering and monitoring. Citizen science draws on the “collective strength and knowledge of the public to gather and analyze data” to answer and address environmental and public health questions (US EPA 2019a). For example, Alabama Water Watch is comprised of resident volunteers 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 activities (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).³⁹ 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).

Citizen science draws on the “collective strength and knowledge of the public to gather and analyze data” to answer and address environmental and public health questions.

Other important strategies are to **provide sufficient funding** for community collaborators and local knowledge holders to engage in knowledge co-production and sharing and **identifying both opportunities and potential barriers and capacity constraints. Devising ways to overcome those barriers and capacity challenges through collaboration at the outset** is also important.

Table 27 lists the four strategies for inclusiveness in the use of climate data, projections, and assessments in rural climate, water, and sanitation presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.



³⁹ The stream use classifications in the state of Alabama designate what function a water body can be used for, such as Fish and Wildlife or Public Water Supply. These classifications are based on the water quality of the water body (Alabama Legislative Services Agency 1967).

TABLE 27. Strategies, Resources, and Case Examples for Inclusiveness in the Use of Climate Data, Projections, and Assessments in Rural Climate, Water and Sanitation

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Use an end-to-end co-production approach in assessing climate risks to include rural 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. 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.	• Harlan County Water Resilience Toolkit (Livelihoods Knowledge Exchange Network 2024c) (1) • Crowdsourcing Climate: Citizen Science and the National Climate Assessment (US Global Change Research Program, n.d.) (2) • Enabling Citizen Science Programs at Environmental Agencies (Environmental Law Institute 2020) (2) • FloodWise Community Assistance Program (Headwaters Economics, n.d.) (3, 4)	• LiKEN Water Collaboratory (Livelihoods Knowledge Exchange Network, n.d.-b) (+) • Alabama Water Watch (Alabama Cooperative Extension System, n.d.) (2) • Friends of the Rouge community science data collection (Friends of the Rouge, n.d.) (2) • Missouri Stream Team (Missouri Stream Team, n.d.) (2) • Increasing community capacity to reduce flood risk in Three Forks, Montana (Smith 2021) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

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 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 by 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). 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; Kimmerer 2013). A holistic approach refers to one that considers the interconnectedness of water systems, ecosystems, and human well-being (Kimmerer 2013).

The integration of local, place-based knowledges and Indigenous knowledges alongside technical data and information holds immense value. Recognizing and incorporating these perspectives can also lead to more holistic and culturally appropriate solutions that foster community resilience and environmental stewardship (Hill et al. 2020; J. Maldonado et al. 2016).

The integration of local, place-based knowledges and Indigenous knowledges alongside technical data and information holds immense value.

One strategy to incorporate rural knowledges and ways of knowing in water and sanitation management is to **ensure that local experts and knowledge holders are consulted and take on leadership roles in community research, data collection, and monitoring efforts**. An example of this is the ANTHC's Climate Change Health Assessment, which 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. They engaged 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. ANTHC's report, [The Unmet Needs of Environmentally Threatened Alaska Native Villages: Assessment and Recommendations](#), provided additional recommendations for collecting community specific data and conducting collaborative risk assessments in rural Alaska Native communities. This type of collaboration between government agencies, Indigenous communities, and local stakeholders has led to initiatives that integrate traditional ecological

knowledge with conventional Western scientific approaches (Cajete 2000). This integration enhances the adaptive capacity of rural communities to address water-related challenges exacerbated by climate change, such as droughts, flooding, and water quality issues (Berkes 2012; McNeeley 2014).

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). This inherently implies the mindful integration of local knowledges (Klenk et al. 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 (Berkes 2012; J. Maldonado et al. 2016; Simpson 2004; K. P. Whyte 2018).

As discussed in [Section 9.2](#), the Pacific Institute, RCAP, and LiKEN’s collaborative project [Water and Climate Equity in Rural Communities in the US](#), researchers used methods in Participatory Action Research in Central Appalachian communities for documenting and visualizing participant knowledge. These included such methods as collaborative timeline creation, social and power mapping,⁴⁰ stakeholder assessments, and transect walks,⁴¹ among others, to understand local climate impacts and resilience (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 needed that led to tools such as the [Harlan County Water Resilience Toolkit](#). 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 from irresponsible sharing of any potentially harmful or sensitive data or information. This also helps to prevent exploitative and extractive practices (David-Chavez and Gavin 2018). [The Tribal Adaptation Menu](#) offers guidance on respectful community engagement in climate adaptation planning (Tribal Adaptation Menu Team 2019). The guidance outlines protocols to honor and respect local knowledge holders to ensure transparency in data ownership and use. It emphasizes that knowledge holders should control how their information is shared. While this resource is focused on integrating Indigenous knowledges, culture, and values into climate planning, it can help inform respectful engagement and data collection with rural communities more broadly. The Status of Tribes and Climate Change Volume 2 report also provides guidance on recognizing and protecting Indigenous knowledges in climate adaptation initiatives (Status of Tribes and Climate Change Working Group 2025).

40 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.-a).

41 Transect walks are guided walks through a community involving residents to observe, document, and analyze built and environmental conditions. They are often used to create a transect map and inform local planning efforts (Catalytic Communities, n.d.).

These strategies can help to overcome several barriers and challenges that 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 are significant problems with the extraction of local knowledge without understanding issues of context and culture, power dynamics, and intellectual property (David-Chavez and Gavin 2018; Klenk et al. 2017). If local knowledge is to inform policy, it cannot be abstracted as “data” divorced from people and places — their cultural and historical context and life experiences (Cruikshank 2001).

Table 28 lists the three strategies to incorporate local and diverse knowledges with technical data in climate, water, and sanitation management presented in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 28. Strategies, Resources, and Case Examples to Incorporate Local and Diverse Knowledges with Technical Data and Information in Climate, Water, and Sanitation Management

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left. A plus sign indicates the resource or case example applies to all strategies.</i>		
1. Ensure that local experts and knowledge holders 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. 3. Use appropriate protocols and agreements to protect local knowledge and rural communities.	• Local Environmental Observer Network (LEO Network, n.d.) (1, 2) • LiKEN Community Engagement Guide: Participatory Action Research Methods (Livelihoods Knowledge Exchange Network 2024b) (2) • The Tribal Adaptation Menu (Tribal Adaptation Menu Team 2019) (+) • Guidelines for Considering Traditional Knowledges in Climate Change Initiatives (US Climate Resilience Toolkit, n.d.-a) (+) • Status of Tribes & Climate Change Report, Volume 2 (Status of Tribes and Climate Change Working Group 2025) (+)	• Water and Climate Equity in Rural Communities in the United States Project (Pacific Institute, n.d.) (+) • The Unmet Needs of Environmentally Threatened Alaska Native Villages: Assessment and Recommendations (Alaska Native Tribal Health Consortium 2024) (+) • 1854 Ceded Territory Climate Change Vulnerability Assessment and Adaptation Plan (Stults et al. 2016) (1) • Incorporation of local and regional knowledges into drought assessment in NW Colorado (McNeeley 2014) (1, 2) • Louisiana’s Comprehensive Master Plan for a Sustainable Coast (State of Louisiana 2017) (1, 2) • Community-engaged participatory climate research with the Pyramid Lake Paiute Tribe (Chew and Chief 2023) (2) • Yukon River Inter-Tribal Watershed Council Climate Adaptation Strategies (Yukon River Inter-Tribal Watershed Council 2022) (1, 2)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

9.4. EQUITABLE DATA AND INFORMATION TRANSLATION, COMMUNICATION, AND DISSEMINATION

Attribute description: Data and information collection centers the needs and perspectives of rural communities and is shared openly and in culturally appropriate formats and languages that are accessible to rural communities.

There are several factors in the US that contribute to a lack of awareness about the water access gap and climate change (Brown et al. 2023; Roller et al. 2019). A key factor is the absence of reliable data, made worse by the US Census Bureau's decision to remove a key question on plumbing access from the American Community Survey. This change is expected to result in undercounting households with incomplete plumbing by approximately 39,000, potentially excluding them from housing and infrastructure decisions and funding programs (Davis Henderson 2019). Historical classism and racism also play a role, as low-income and non-White populations have long faced systemic neglect regarding water and sanitation access (Brown et al. 2023). For example, in 2020, the Indian Health Services Home Inventory Tracking System identified 12.5% (approximately 52,000) of American Indian/Alaska Native homes lacked adequate sanitation, compared to less than 0.4% of the general US population (Status of Tribes and Climate Change Working Group 2021; US Census Bureau 2022a). Despite this disparity, federal funding has not prioritized safe drinking water or wastewater for Tribes. Additionally, fear of reporting poor water and sanitation conditions prevents many from coming forward. Families may fear deportation due to immigration status or worry about potential child welfare interventions (21 states classify a lack of running water as child neglect).

Addressing these challenges is critical for building climate-resilient water and sanitation systems in rural areas. Without accurate data, gaps in infrastructure and water access are difficult to identify. Historical inequities further exacerbate vulnerabilities due to a lack of resources to adapt to climate-related water challenges. In addition, fear-driven underreporting prevents timely interventions that could improve resilience. 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.). These communication gaps 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. Ensuring equitable data collection and prioritizing historically excluded communities is essential for developing sustainable, climate-adaptive water and sanitation solutions.

Ensuring equitable data collection and prioritizing historically excluded communities is essential for developing sustainable, climate-adaptive water and sanitation solutions.

Strategies that **embrace uncertainty by focusing on known drivers and other climate related impacts** can reframe uncertainty as risk and make climate challenges feel more tangible and actionable rather than abstract. Additionally, **presenting a positive vision for the future and emphasizing ongoing progress** — rather than relying on fear — can reframe challenges in a way that demonstrates how stakeholders' actions can make a difference in managing risks and driving change and creates a more persuasive message (Moser and Dilling 2004). For example, the [Exploratory Scenario Planning for Water Resilient Agriculture](#) project in Sulphur Springs Valley, Arizona combines both strategies by bringing together diverse stakeholders and trusted experts to proactively navigate various changes in groundwater availability and outcomes rather than focusing on a single, presumed future (Figure 21) (Gupta et al. 2024). This type of community-led exploratory scenario planning, guided by trusted experts, empowers stakeholders to identify common goals and develop informed, flexible, and actionable strategies. From this, the [Sulphur Springs Water Alliance](#) was born — a community-driven initiative dedicated to the ongoing process to balance the local water budget in the rural west and highlights resilience, responsibility, and innovation.

FIGURE 21. Photos from Exploratory Scenario Planning for Water Resilient Agriculture



Fostering community synergy in the full group setting and breakout sessions for facilitated discussions on diverse scenarios and outcomes related to uncertain water supplies and demands at the Sulphur Springs Valley Ag XSP workshop. Photos courtesy of Babbitt Center for Land and Water Policy.

Source: Arizona State University, n.d.-a; Photo credit: Babbitt Center for Land and Water Policy, a center of the Lincoln Institute of Land Policy

These types of exploratory scenario planning strategies allow **stakeholders to navigate uncertainty** by analyzing multiple possible futures, identify key drivers of change, and develop flexible policies that align resources effectively. This in turn helps to create a **positive vision for the future** by fostering proactive planning, resilience-building, and community collaboration rather than relying on fear to manage risks. Similarly, the [Verde Valley Water Workshop](#) brought together nearly forty community members, including municipal leaders, educators, youth, and NGOs to develop community-driven projects and to create a shared understanding of water issues, fostering intergenerational dialogue. These and other local workshops are facilitated by Arizona State

University's Project Cities program and funded by [Arizona Water Innovation Initiative's](#) program, [Impact Water — Arizona](#), to generate solutions for water and climate resilience across the state.

These examples highlight strategies that prioritize inclusive, place-based solutions that align with the distinct cultural and socioeconomic contexts of rural communities. They focus on proactive, collaborative problem-solving that **connects climate issues to real-world concerns and frames challenges within their local cultural, socioeconomic, or geographic context**. 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).

Another strategy utilizes **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).

Storytelling through blogs, social media, news articles, immersive journalism, data visualization, and other art forms can inspire and create positive changes by presenting information within the cultural, socioeconomic, or geographical context to tell a more relevant and impactful story. Weaving factual information with compelling narratives humanizes data and information through personal or community experiences to create empathy and a shared experience.

For example, TIME magazine's September 2024 story, "[This is Life in America's Water Inequality Capital. It Might Be About to Change](#)," compared the water and sanitation challenges of two rural communities, the Navajo Nation and Utah's Washington County. The piece provided a compelling story readers can emotionally connect with by contrasting the daily hardships of one community's access to water — hauling water for miles or paying high costs — with the ease of water access in nearby communities. Similarly, the site Run Dry tells personal stories of how rural communities in California struggle to remain connected to water supplies by using a blend of short films, personal stories, images, and data visualization. The project shares personal stories of living without access to water or living with contaminated water combined with success stories of communities gaining access to water systems (Stein 2020). Arizona State University's [Narrative Storytelling Initiative](#) addresses critical water challenges in the state through the [Water Narratives](#) project. This project uses a variety of platforms including music, digital sound, video, theatre, dance, and photos, and includes stories such as "Water of the Salt River Pima-Maricopa Indian Community."

Storytelling through blogs, social media, news articles, immersive journalism, data visualization, and other art forms can inspire and create positive changes by presenting information within the cultural, socioeconomic, or geographical context to tell a more relevant and impactful story.

Museum exhibits, such as The Smithsonian's "[Water/Ways](#)" can also help to deepen engagement and bring awareness to water challenges in rural America. Traveling exhibitions are brought directly to rural communities to tell the story of water as a critical resource. Complementary exhibits by each

host city are developed to tell their own unique stories on what water means culturally, socially, and spiritually within their own communities.

Finally, there has been a proliferation of misinformation and disinformation, especially with use of social media. As such, equitable data sharing, translation, and dissemination depend on the **use of credible, evidence-based climate change data and information to counter misinformation and disinformation.**⁴² Climate change denialism, contrarianism, and skepticism are all forms of climate change misinformation (Treen, Williams, and O'Neill 2020). Climate change denialism is more prevalent where local economies are highly dependent upon fossil fuels, like some rural communities in the US (Gounaridis and Newell 2024). Diamond and co-authors (2020) found that urban areas in the US are more likely to support climate action than rural areas.

Even when rural residents are concerned about climate change, they are often reluctant to talk about it due to the political polarization of the topic (Diamond, Bonnie, and Rowe 2020). In the age of social media, the spread of climate change misinformation is more prevalent and likely playing a significant role in exacerbating political polarization, inaction, and stalled support for climate-related policies or actions (Treen, Williams, and O'Neill 2020). Higher rates of climate skepticism are linked to increased flood risks, especially in rural areas of the US (Gounaridis, Waweru, and Newell 2024). This highlights the serious consequences of spreading mis- or disinformation about climate change. Rural water and sanitation decision makers can benefit from utilizing credible, ideally peer-reviewed sources of information when developing climate adaptation initiatives. This can help slow the spread of misinformation and counter climate change skepticism. For example, rural communities can use legitimate resources like [Skeptical Science](#) to better understand climate skepticism and educate others about climate change (Skeptical Science, n.d.). The [US National Climate Assessment](#) is another source of credible, peer-reviewed science and information aimed at policy and decision makers.

In the age of social media, the spread of climate change misinformation is more prevalent and likely playing a significant role in exacerbating political polarization, inaction, and stalled support for climate related policies or actions.

To enhance communication and knowledge exchange between communities and decision makers and to reframe climate and water discussions, the strategies shared, along with resources and case examples, are included in Table 29 below.

⁴² According to Dictionary.com, misinformation is “false information that is spread, regardless of whether there is intent to mislead” (Dictionary.com 2025b). Disinformation is closely related, with definitions describing it as false information that is deliberately spread with the intent to mislead (American Psychological Association, n.d.; Dictionary.com 2025a).

TABLE 29. Strategies, Resource, and Case Examples to Achieve Equitable Data and Information Translation, Communication, and Dissemination in Rural Climate, Water, and Sanitation

STRATEGIES	RESOURCES/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals, because audiences tend to reject fear-based messages. 2. Connect climate issues to real-world concerns that people already care about by framing challenges within their local cultural, socioeconomic, or geographic context and by aligning with their values and worldviews. 3. Embrace uncertainty by focusing on what is known and highlighting scientific consensus, while remaining open to new and improved information. 4. Utilize storytelling to effectively convey data, acknowledging and respecting the emotions and psychology of the target audience while validating their experiences. 5. Use credible sources when incorporating climate change into rural water and sanitation initiatives to provide clarity and slow the spread of misinformation.	• Speaking to the Heart: Storytelling for Social Change (Water Hub 2024) (4) • Just Infrastructure: Lessons on water infrastructure storytelling (Bucci 2024) (4) • Skeptical Science (Skeptical Science, n.d.) (5) • US National Climate Assessment (Jay et al. 2023) (5) • Climate Disinformation Resources (350 New Mexico, n.d.) (5)	• Early Warning Information Increases Options for Drought Mitigation in Nebraska (US Climate Resilience Toolkit 2015) (2) • Exploratory Scenario Planning for Water Resilient Agriculture (Gupta et al. 2024) (1, 2, 3) • La Paz County Rural Groundwater Resilience Workshop (Kearns 2025) (1, 2, 3) • Verde Valley Water Workshop (Randall 2024) (1, 2, 3) • Narrative Storytelling Initiative, Water Narratives (Arizona State University Julie Anne Wrigley Global Futures Laboratory, n.d.) (1, 4) • Run Dry (Diekman, n.d.) (2, 4) • Incorporation of local and regional knowledges into drought assessment in NW Colorado (McNeeley 2014) (1, 2, 4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

9.5. KNOWLEDGE AND INFORMATION SUMMARY

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 rural 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 rural US. 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, this integration can help build capacity for rural communities to achieve equitable, climate-resilient water and sanitation.





10. Capacity Building

This category describes ways to build the capacity of rural water and sanitation professionals, communities, and households with the training, skills, and support they need to equitably adapt to climate change.

An essential component of preparing for and responding to the impacts of climate change is building and maintaining the capacity of rural communities and institutions to effectively manage water and sanitation systems (Ivey et al. 2004). Capacity building plays an important role in ensuring rural water and sanitation professionals have the training, skills, and support they need to capably prepare for and respond to the impacts of climate change. Capacity building strategies such as recruiting and maintaining a robust workforce, co-developing resilience strategies with community members, and creating mutual aid partnerships with interdependent sectors such as energy, housing, transportation, agriculture, and communications, all help to build local capacity and climate resilience. To be effective, it is important that strategies to build capacity in rural communities are designed and implemented in culturally appropriate ways, attuned to local contexts, and co-created with community members and stakeholders (Ramanadhan et al. 2021).

This section highlights four attributes of equitable and climate-resilient capacity building strategies for rural water and sanitation systems. They are:

1. climate-literate, robust, water and sanitation workforce, representative of their community;
2. rural community empowerment in water and climate decision making;
3. capacity to work with interdependent sectors for climate resilience; and
4. TMF skills for equitable climate resilience.

This section includes case examples and resources to support rural communities to build capacity to support equitable, climate resilient water and sanitation systems (see the table at the end of each attribute for a compilation of resources.) However, not all strategies have corresponding case examples in this report. Where possible, we include strategies that have been co-developed with community members. For further details and additional case examples from contexts beyond rural areas, refer to Section 10 on capacity building in [Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities](#) (McNeeley et al. 2025).

10.1. CLIMATE-LITERATE AND ROBUST WATER AND SANITATION WORKFORCE REPRESENTATIVE OF THEIR COMMUNITY

Attribute description: The water and sanitation workforce in rural communities is robust, climate-literate, and representative of the communities being served.

As climate change accelerates, a robust, climate-literate, and representative water and sanitation workforce will be essential to integrating and maintaining water and sanitation system access in rural communities. A robust workforce helps to ensure there are enough qualified sector professionals to fill needed positions, which is particularly important in small and rural water systems where workforce shortages are common (Rosen et al. 2018; Rural Community Assistance Partnership 2019; Water Resources Alliance 2024).

Climate literacy is defined as “an understanding of how the climate system works, how human actions influence climate change, and how climate change influences people and other parts of the Earth system” (US Global Change Research Program 2024). It is important that rural workforces are climate-literate and able to use and understand climate information and projections to inform water planning and decision making (Lowrey, Ray, and Webb 2009). For example, climate literacy can build the capacity of rural water managers to understand the likelihood of climate risks, such as droughts, floods, and extreme temperatures, and take appropriate steps to reduce the vulnerability of water systems to these impacts.

A representative workforce is when water management professionals reflect the culture and lived experience of communities they serve. A representative workforce is often better able to understand and integrate community needs into management, planning, and disaster response (US Water Alliance 2017).

With a climate-literate, robust, and representative workforce in place, rural communities are more likely to have the capacity to manage, operate, and maintain equitable and climate-resilient water and sanitation systems and to make informed water management decisions under a wide range of conditions. To achieve this, **trainings, programs, and tools aimed at increasing climate literacy** can bolster water and sanitation managers’ and water management decision-makers’ ability to prepare for and respond to climate impacts (Kirchhoff 2013; Powers, DeWaters, and Dhaniyala 2021). For example, the NOAA Climate Adaptation Partnerships Program (formerly Regional Integrated Sciences and Assessments) is an applied research and engagement program that works to expand community capacity to build equitable climate resilience in both rural and urban communities in the US (NOAA 2024).

One exemplary Climate Adaptation Partnerships Program partnership is Project Big Wood in rural Idaho. The Climate Impacts Research Consortium, based at Oregon State University, worked with community members in Big Wood to help them understand, prepare for, and respond to the impacts of climate change on local water resources by co-creating a series of climate simulations. These simulations demonstrated how climate change, changes in the local economy, and policy responses could impact local water resources. Participation in the program increased the climate literacy of local water management decision-makers — including policymakers, local farmers, and others —

and helped them to understand and apply the relevant information from the simulations. Increased climate literacy and new tools can together bolster the ongoing capacity of decision-makers to make more informed choices around water management to support climate resilience (Oregon State University 2018).

FIGURE 22. WaterNow Alliance’s 2024 Emerging Leader Convening in Philadelphia



Source: O'Donnell and Koehler 2024

A strategy to support a representative and climate-literate rural workforce is through participation in **workforce recognition and networking initiatives for rural utility leaders, especially for those from underrepresented groups**. For example, WaterNow Alliance’s Emerging Leader Awards Program offers recognition for mid-level water and wastewater utility staff who are advancing innovative, sustainable, equitable, and climate-resilient water solutions in their communities (see Figure 22) (O'Donnell and Koehler 2024; WaterNow Alliance, n.d.-b). 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 future generation of water leaders. The program prioritizes those from diverse, underrepresented backgrounds to help ensure the water and sanitation workforce is representative of the community being served (WaterNow Alliance 2024). The Center for Water Security and Cooperation offers a similar program called the Water Access and Equity Lab for emerging water utility leaders (The Center for Water Security and Cooperation, n.d.). By building their capacity to address complex issues around climate and equity, program participants are empowered to bring these insights back to rural utilities and drive meaningful change.

A strategy to support a water and sanitation workforce that is robust and representative of the community being served is to **educate students and other career-ready individuals about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.** Throughout the US, there is a shortage of water and wastewater sector professionals, an issue that is more pronounced in some rural communities (Water Resources Alliance 2024; Rural Community Assistance Partnership 2019). Workforce shortages may reduce the capacity of rural communities to prepare for and respond to the impacts of climate change. Compounding this concern, many existing professionals are set to retire within the next decade (Morrissette, n.d.; Rosen et al. 2018). One example of this strategy is the Water WORCs Internship Program developed by West Virginia University and partners to address these concerns in rural communities in West Virginia, Kentucky, Tennessee, and Virginia (West Virginia University Institute of Sustainability and Energy, n.d.; Morrissette, n.d.; Appalachian Community Technical Assistance and Training, n.d.). The goal of the program is to “encourage students in high school, technical school, or college to pursue careers in the water sector in their rural, Appalachian communities, many of whom need qualified technical staff” (West Virginia University Institute of Sustainability and Energy, n.d.). The paid internship program offers participants hands-on experience in water and sanitation jobs and an opportunity to accrue certification hours needed for employment. Through recruiting and preparing residents for careers in water and sanitation, this type of program helps ensure that rural utilities have the current and future capacity to address the impacts of climate change.

Workforce shortages may reduce the capacity of rural communities to prepare for and respond to the impacts of climate change.

Table 30 lists three strategies for climate-literate, robust, and representative water and sanitation workforce shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities

TABLE 30. Strategies, Resources, and Case Examples for Climate-Literate, Robust, and Representative Water and Sanitation Workforce in Rural Communities

STRATEGIES	RESOURCE/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Take advantage of climate adaptation training, programs, and tools 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 groups. 3. Educate students and other career-ready individuals about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.	• Climate Adaptation Partnership Program (NOAA 2024) (1) • Climate Hubs Climate Literacy and Training (USDA Climate Hubs, n.d.-b) (1) • Creating Resilient Water Utilities (US EPA 2024b) (1) • US Climate Resilience Toolkit Online Training for Water Utilities (US Climate Resilience Toolkit, n.d.-d) (1) • WaterNow Alliance Emerging Leader Awards Program (WaterNow Alliance, n.d.-b) (1, 2) • Water Access and Equity Lab (The Center for Water Security and Cooperation, n.d.) (1, 2) • Headwaters Economics Rural Capacity Map (Headwaters Economics 2024) (1, 3) • Water WORCS Internship Program (Appalachian Community Technical Assistance and Training, n.d.) (3) • NWRA Apprenticeship Program (National Rural Water Association, n.d.-b) (3)	• Big Wood Basin Alternative Futures (Oregon State University 2018) (1) • Climate Change Adaptation workshop with the Dixie National Forest (USDA Climate Hubs, n.d.-a) (1)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain

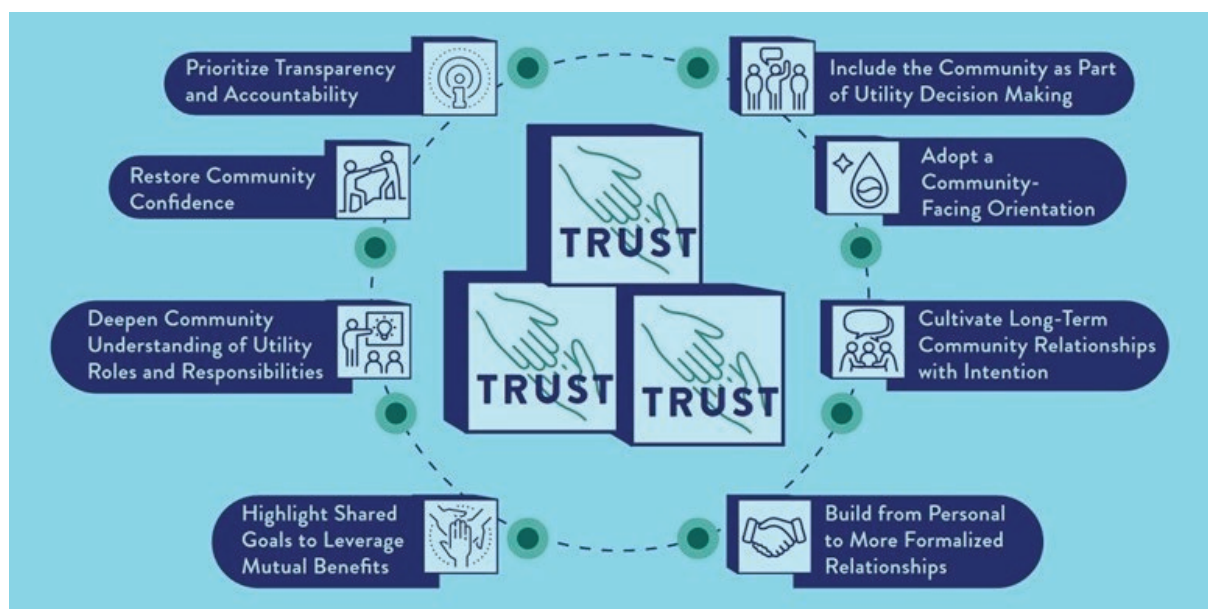
10.2. RURAL COMMUNITY EMPOWERMENT IN WATER, CLIMATE, AND SANITATION DECISION MAKING

Attribute description: Rural communities are supported and have sufficient capacity for inclusive, equitable, and culturally appropriate participation in climate, water, and sanitation decision making.

The meaningful inclusion of rural community members in water, climate, and sanitation decision making requires the creation of culturally appropriate, equitable, and inclusive participation mechanisms. As rural communities are among the groups that experience climate impacts first and worst, centering the voices, needs, and lived experiences of community members is critical to achieve equitable and locally relevant climate resilience strategies (Taylor et al. 2024; Pacific Institute and DigDeep 2024). For related strategies, also see [Section 7.2](#).

One strategy to enhance the participation of rural community members is to **build trust between rural community members and the water and wastewater utilities serving them by promoting transparency, inclusivity, and community engagement**. In US locations where water is not safe, community members are often less likely to trust engineers, water utility staff, and public health officials (Meehan et al. 2020). This may be a particular concern in rural areas where water systems are more likely to be in violation of the SDWA (Allaire, Wu, and Lall 2018). In such instances, having the capacity to build trust with community members is an important step toward opening lines of communication and engagement. Resources such as Building Blocks of Trust: Creating Authentic and Equitable Relationships Between Community Organizations and Water Utilities can be used to facilitate rural community members and utilities overcoming barriers to trust (River Network and WaterNow Alliance 2021). The report describes eight building blocks of trust, shown in Figure 23, which include:

1. prioritizing transparency and accountability,
2. restoring community confidence,
3. deepening community understanding of utility roles and responsibilities,
4. highlighting shared goals to leverage mutual benefits,
5. including the community as part of utility decision making,
6. adopting a community-facing orientation,
7. cultivating long-term community relationships with intention, and
8. building from personal to more formalized relationships.

FIGURE 23. Building Blocks of Trust from River Network and WaterNow Alliance

Source: River Network and WaterNow Alliance 2021

This guide can be tailored to support utilities in creating culturally appropriate and inclusive mechanisms for building or establishing trust with the communities they serve (River Network and WaterNow Alliance 2021). This trust is a foundational element for more equitable and inclusive participation of communities in climate and water decision making.

Furthering trust between community members and utilities can open the door for more direct collaboration on climate planning and adaptation efforts. One strategy is **to use community-based participatory research and an asset-based approach⁴³ that supports the co-production of information and co-development of adaption strategies and educational tools.** For example, in a collaborative project between the Pacific Institute, RCAP, and LiKEN, participatory action research (PAR) methods were used to understand how residents in Kentucky’s Harlan and Martin Counties experienced extreme weather in their communities’ water systems (Taylor et al. 2024). PAR is a form of community-based participatory research that draws on well-established methods for conducting and empowering research that mobilizes local knowledge while maintaining high standards of scholarly vigor. The partners in Kentucky used multiple PAR methods, including collaborative timeline creation, power mapping,⁴⁴ and relative ranking⁴⁵ to empower residents to co-produce and co-own the knowledge creation and sharing process. The information gathered through these methods was used to inform a tailored Water Resilience Toolkit that provides guidance to prepare for water and climate disasters (Livelihoods Knowledge Exchange Network, n.d.). This process, and the toolkit it

43 An asset-based approach centers existing capacities in communities to build on success and unique local realities (Taylor et al. 2024).

44 Power mapping helps visualize the current power structure to empower residents 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.-a)

45 Relative ranking is an exercise that allows participants to list various services or resources that are important to them and rank them in order of importance. This method is useful to understand the priorities and preferences of participants to inform decision making and priorities (Livelihoods Knowledge Exchange Network, n.d.-a)

produced, helps to build the capacity of residents to actively engage in climate-resilient water and sanitation decision making.

Developing partnerships between rural community members, community-based organizations, and other nonprofit organizations to advance community-driven water and sanitation policies is another strategy to increase community capacity to advance equitable outcomes in water and sanitation decision making. For example, community members from the Cochran colonia outside of El Paso, Texas, have undertaken a decades-long advocacy campaign to receive water infrastructure in their community, which was developed without basic infrastructure (McNeeley et al. 2025; DigDeep, n.d.-a). Community members entered a partnership with DigDeep, A.Y.U.D.A. Inc., the University of Texas at El Paso, local government officials, and utility leaders to help bring water to the colonia. The partnership enhanced the capacity of community members to advance the advocacy campaign. With community members guiding the process, partner organizations were able to leverage their resources and expertise to help the community access grants and infrastructure. A community-led approach is central to these kinds of partnerships because it helps ensure that advocacy is focused on infrastructure that is tailored to local needs and is climate resilient. The project in the colonias demonstrates how partnerships can be a powerful means to enhance community capacity by combining resources and expertise to enhance climate resilience and achieve community goals.

Table 31 lists three strategies for empowerment in water and climate change decision making for rural communities. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 31. Strategies, Resources, and Case Examples for Empowerment in Water and Climate Decision Making for Rural Communities

STRATEGIES	RESOURCE/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Build trust between rural communities and water and wastewater utilities serving them by promoting transparency, inclusivity, and community engagement.	• Building Blocks of Trust: Creating Authentic and Equitable Relationships Between Community Organizations and Water Utilities (River Network and WaterNow Alliance 2021) (1) • Water Resilience Toolkit (Livelihoods Knowledge Exchange Network, n.d.) (2)	• Water and Climate Equity in Rural Water Systems in the United States (Taylor et al. 2024) (2) • Grassroots Campaign for Water Justice (Virginia Interfaith Power & Light, n.d.) (3) • Colonias Water Project (DigDeep, n.d.-a) (3)
2. Co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with rural communities using community-based participatory research and an asset-based approach.		
3. Develop partnerships between rural community members, community-based organizations, and other nongovernmental organizations to advance community-driven water and sanitation policies.		

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain

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 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, housing, transportation, agriculture, and communications (University of New Mexico Southwest Environmental Finance Center 2024). For example, the energy sector relies on water for energy production and generation, and water operation facilities and delivery systems require energy (University of New Mexico Southwest Environmental Finance Center 2024). Disruption in any sector can lead to a cascade of effects in other sectors, potentially resulting in widespread consequences for rural communities. 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). Building the capacity to work across interdependent sectors is an opportunity for water and sanitation managers to better understand, prepare for, and address compound risks and respond to climate hazards (Szinai et al. 2021).

One strategy to increase the capacity to work with interdependent sectors is for water and wastewater managers to use **existing tools and resources to understand sector interdependencies and initiate collaborations**. For example, the 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 (US EPA n.d.-b). This is accomplished by starting conversations between utilities and communities to identify the actions and resources needed to increase climate resilience. This resource also includes suggested activities and goals for community workshops, such as facilitating breakout discussions detailing a real or hypothetical climate event and identifying methods for integrative water utilities in community planning (see [Section 7.5](#)).

Building the capacity to work across interdependent sectors is an opportunity for water and sanitation managers to better understand, prepare for, and address compound risks and respond to climate hazards.

Another strategy to build capacity to work with interdependent sectors is to **foster partnerships, mutual aid, and support between neighboring water and wastewater utilities**. For instance, the University of New Mexico 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 highlights the Water/Wastewater Agency Response Network (WARN) systems, which are state-level networks of utilities

willing and able to help other utilities respond to and recover from emergencies (American Water Works Association 2024; US EPA 2015f). Participating utilities have increased capacity to respond to climate disasters through mutual aid. For example, during a snowstorm in rural Detroit, Oregon, the local water treatment plant lost power and was running on a short-term generator, but high snow berms made it impossible for the utility staff to get the supplies they needed to keep the plant running (American Water Works Association 2008). As a WARN member, Detroit was able to quickly get support from another city that shared backhoes to clear the roads, allowing delivery of propane for their generators keeping the water plant operable. This demonstrates how WARN can establish mutual aid networks beyond the water sector to support the capacity of interdependent sectors. Additionally, this is an example of how mutual aid and support between nearby communities can enhance capacity during emergencies caused by the interdependencies of the water sector with other sectors, like energy and transportation.

For rural communities looking to build local or regional climate resilience, approaches that **foster education, information sharing, and communication across sectors** can enhance preparation and response to climate impacts. For example, Michigan State University and the Michigan Department of Health and Human Services created the Climate and Health Adaptation Planning Guide for Michigan Communities to help rural, suburban, and urban communities across Michigan and the larger Great Lakes region collaborate on climate adaptation planning across sectors (Michigan State University and Michigan Department of Health and Human Services 2020). The guidebook was created with input from the community, representatives from local, county, and regional government, and at least 28 local organizations. It includes coordinated cross-sector plans to prepare for climate impacts such as flooding through education campaigns, coordinated emergency response plans, inventory mapping of vulnerable infrastructure, and capital improvement plans (Michigan State University 2019).

The guide was piloted in rural Marquette, Michigan as the Marquette Area Climate and Health Adaptation Guidebook (Michigan State University 2019). In the county, this effort facilitated building adaptive capacity of the Marquette County Climate Adaptation Task Force, the Marquette County Health Department, the Superior Watershed Partnership, and other community groups to respond to climate-related health impacts in an equitable manner (Michigan State University and Michigan Department of Health and Human Services 2020).

Table 32 lists three strategies to support the capacity to work with interdependent sectors shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

For rural communities looking to build local or regional climate resilience, approaches that foster education, information sharing, and communication across sectors can enhance preparation and response to climate impacts.

TABLE 32. Strategies, Resources, and Case Examples for Capacity to Work with Interdependent Sectors for Climate Resilience in Rural Communities

STRATEGIES	RESOURCE/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Leverage existing tools and resources, such as the 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. 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.	• Community-Based Water Resiliency Guide (US EPA, n.d.) (1) • Water Sector Interdependencies: Small and Medium-Sized System Guidance (University of New Mexico Southwest Environmental Finance Center 2024) (2) • Water and Wastewater Emergency Response Network (US EPA 2015f) (2) • Climate and Health Adaptation Planning Guide for Michigan Communities (Michigan State University and Michigan Department of Health and Human Services 2020) (3)	• Economic Benefits of Forming and Participating in a Water/Wastewater Agency Response Network (WARN) - Detroit, Oregon case study (American Water Works Association 2008) (2) • North Carolina Emergency Operations Centers Activation and Intrastate Mutual Aid During Hurricane Florence (FEMA n.d.) (2) • Marquette Area Climate and Health Adaptation Guidebook and pilot project (Michigan State University 2019) (3)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.

10.4. TECHNICAL, MANAGERIAL, AND FINANCIAL SKILLS FOR EQUITABLE CLIMATE RESILIENCE

Attribute description: Water managers are empowered with the technical, managerial, financial, and leadership skills to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.

Technical, managerial, and financial (TMF) and leadership skills can bolster the capacity of rural water and sanitation managers to maintain equitable and climate-resilient systems. As climate change alters water quantity, quality, and demand, strong TMF capacity is central to achieving and maintaining compliance with national safe drinking water regulations (Pacific Institute and DigDeep 2024; US EPA 2015e; US EPA 2015i). Rural and small water systems, in particular, can benefit from TMF skills, as these systems are more likely to experience barriers to maintaining regulatory compliance (Dobbin et al. 2023; Statman-Weil, Nanus, and Wilkinson 2020; US EPA 2015e;

Vedachalam, Male, and Broaddus 2020; Allaire, Wu, and Lall 2018). Leadership skills also support the capacity of rural water and sanitation managers to navigate the complex social, economic, regulatory, environmental, cross-boundary, and multi-stakeholder contexts of water and sanitation management within a changing climate (International Water Centre, n.d.).

One strategy to increase TMF capacity in rural communities is to **require TMF trainings for water board members**. Training of water board members has been found to contribute to more investment in water system maintenance, helping maintain higher levels of compliance with SDWA regulations (Gasteyer and Taylor 2009). For example, the state of Mississippi requires training for all elected or appointed board members of public community water systems. The initiative was spearheaded by small system operators in partnership with the Mississippi Rural Water Association. As a result of the program, board members are held accountable and are more likely to invest in upgrades to treatment facilities and infrastructure, which is important for small and rural water systems in need of upgrades. This program is linked to high levels of compliance with SDWA rules and regulations across the state, and is enforced through capacity development inspections that evaluate management factors, including financial records and rate raises (Gasteyer and Taylor 2009). Climate change is directly altering water quality, making it even more difficult for water operators to meet drinking water quality regulations (Pacific Institute and DigDeep 2024). This underscores the importance of building TMF capacity that drives investments in rural water and wastewater systems. Similar training requirements could be mandated in states or municipalities to increase TMF capacity specifically for building resilience to climate change.

Another strategy to increase the TMF capacity in rural communities is to **establish formal and informal social networks to share information and resources** to help overcome capacity challenges and prepare for climate impacts. These networks can be particularly useful for small, rural water and wastewater utilities that have limited access to TMF resources for climate resilience due to financial, geographic, or other constraints (Kettle et al. 2023). In rural western Alaska, for example, limited broadband access, high travel costs, and extreme weather complicate access to remote and in-person trainings and the ability to share parts and equipment. Surveys and interviews with rural water and wastewater managers and service providers in the region found that local nongovernmental networks, such as regional health corporations, the Alaska Rural Water Association, and the Alaska Native Tribal Health Consortium, help to overcome these barriers by providing training and technical assistance at minimal or no cost and facilitating resource and information sharing to support climate resilience (Kettle et al. 2023). Local networks like these are well suited to build capacity to address unique, place-based climate resilience needs.

Another strategy to increase the technical, managerial, and financial capacity in rural communities is to establish formal and informal social networks to share information and resources to help overcome capacity challenges and prepare for climate impacts.

Another strategy for building rural TMF capacity is to consider **consolidation and regionalization of small, underresourced water and wastewater systems**. There are many challenges and potential trade-offs that create reservations about consolidation and regionalization for some rural communities, including political, logistical, and legal barriers; fear of loss of control; and financial challenges like high upfront costs (Landes et al. 2020). While this strategy may not be a good fit for every community, for some it can help address TMF capacity challenges and increase system resilience, particularly when the process is fair, transparent, and inclusive.

In rural Centre County, Pennsylvania, for example, the Oak Hall Water Association Public Water System used consolidation as a strategy to increase TMF capacity. The water system was out of compliance with Pennsylvania's Filter Rule and required filtration of the existing source or an alternative source to achieve compliance (Pennsylvania Department of Environmental Protection, n.d.). With a small customer base and high costs, the system did not have the financial capacity for system upgrades. A study determined that an interconnection with the College Township Water Authority would provide potable water to customers without the burden of financing a large improvement project. These upgrades increase climate resilience because the interconnected system is better equipped to maintain compliance as climate change impacts threaten to alter water quality, quantity, and demand (Pacific Institute and DigDeep 2024; Pennsylvania Department of Environmental Protection, n.d.).

Another strategy to increase TMF capacity in rural communities is to take advantage of **leadership training programs to equip professionals with TMF skills to advance climate-resilient strategies**. For example, several under-resourced and frontline communities in Michigan and Wisconsin are utilizing [the FloodWise Communities Program](#) to receive capacity development and technical assistance to complete stormwater vulnerability assessments and make their stormwater systems more resilient to the impacts of climate change (ICLEI USA 2024). In this program, participating local governments receive technical assistance and training on team building, inclusive community engagement, communications, and climate vulnerability assessments. Participants develop a better understanding of local and regional climate science and impacts, learn to use climate and socioeconomic data in their planning, to incorporate community feedback into their work, and to leverage their assessments to inform local policy and budgets, reduce risks, and seek funding (ICLEI USA 2024).

Table 33 lists four strategies to support TMF skills shared in this section. It also includes resources, tools, and case examples to help rural water and sanitation systems explore opportunities for implementation in their own communities.

TABLE 33. Strategies, Resources, and Case Examples for Technical, Managerial, and Financial Skills for Equitable Climate Resilience in Rural Communities

STRATEGIES	RESOURCE/TOOLS	RURAL CASE EXAMPLES
<i>The bold numbers in parentheses assigned to resources and case examples correspond to the strategies in the column to the left.</i>		
1. Require technical, managerial, and financial (TMF) trainings for water system board members. 2. Establish formal and informal social networks among underserved systems to share information and resources to help overcome capacity challenges and prepare for climate impacts. 3. Consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity. 4. Take advantage of leadership and TMF training and assistance programs to build capacity to advance climate-resilient strategies.	• Circuit Rider Program (USDA n.d.-a) (4) • Resilient, Together: FloodWise Communities Learn & Do Cohorts (ICLEI USA 2024) (4) • Tools for Equitable Climate Resilience: Fostering Community Leadership (River Network, n.d.) (4) • Creating Resilient Water Utilities (US EPA 2024b) (4) • Climate Resilience Evaluation and Awareness Tool (US EPA n.d.-a) (4) • Training and Technical Assistance Program for Rural, Small, and Tribal Wastewater Systems (US EPA 2023g) (4) • Closing America's Wastewater Access Gap Initiative (US EPA 2022c) (4)	• Mississippi's Public Water System Board Management Training Program (Mississippi State University Extension Service, n.d.) (1) • Building Resilience to Extreme Weather and Climate Events in the Rural Water and Wastewater Sectors in Southern Louisiana and Western Alaska (Kettle et al. 2023) (2) • Oak Hall Water Association Water System Interconnection (Pennsylvania Department of Environmental Protection, n.d.) (3) • Three Forks Montana flood risk reduction pilot project (Smith 2021) (4)

Note: Due to changes in the federal government in 2025 the availability of any federal resources or tools listed in this table may be uncertain.



10.5. CAPACITY BUILDING SUMMARY

Capacity building strategies can be implemented to help advance equitable and climate resilient water and sanitation systems in rural communities. For example, when the water and sanitation workforce in rural communities is representative of the community being served, climate-literate, and robust, the workforce will have better capacity to represent community needs and enhance climate resilience. Culturally appropriate, equitable, and inclusive participation mechanisms can bolster the capacity of rural community members to participate in water, sanitation, and climate decision making. When water and sanitation managers have the capacity to coordinate with interdependent sectors, such as energy and transportation, they increase their ability to prepare for climate impacts and enhance resilience. Finally, empowering water managers with TMF skills can increase their capacity to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.



11. Law and Policy

This category describes laws and policies that enable more equitable, climate-resilient construction, operation, and management of rural water and sanitation systems.

Laws create enabling conditions for equitable, climate-resilient rural water and sanitation services and infrastructure. For example, they set rules that govern critical aspects of how water and wastewater systems are designed, built, managed, and operated. Laws create funding and financing programs and direct how those programs can support built or natural infrastructure, technology, capacity building, and other strategies required for equitable climate resilience. They also influence how water and wastewater operators respond to floods, droughts, and other climate disasters. In rural, less-densely populated areas, decentralized infrastructure is more often used to deliver water and wastewater services. Although there are fewer laws and policies governing decentralized water and sanitation systems (e.g. private wells, septic systems) compared to those for centralized water and wastewater systems, laws also create enabling conditions for the households that rely on onsite water and sanitation. These rules — or the lack of or failure to enforce these rules — govern water and sanitation services and infrastructure in both urban and rural areas.

We identified six key attributes of federal, state, and local laws and policies that enable climate change and climate resilience to be incorporated into the construction, operation, and management of water and wastewater services and infrastructure.⁴⁶ These include:

1. laws set structural standards to ensure reliability of services;
2. laws protect rights, allocation, and uses of water for domestic purposes;
3. laws require water and wastewater utilities as well as local and state governments to conduct climate resilience planning;
4. laws require the creation, collection, and publication of information;
5. laws appropriate and equitably distribute funding for water and wastewater services and infrastructure; and
6. laws are enforceable and enforced.

⁴⁶ These attributes may also be applicable to Tribal laws and policies, however, in this report we did not address this area of law.

Here we present some examples of laws and policies that correspond with these attributes, representing the strategies for this category. This section differs from the rest of the report because this is a higher-level review of the laws and policies relevant to the provision of drinking water and sanitation in rural contexts. A forthcoming report on law and policy strategies will be published later in 2025. Therefore, in this report, this section does not have summary tables of the strategies, resources, tools, and rural case examples to be found in the rest of the report. For a more in-depth exploration of the ways that laws and policies that govern water and sanitation services and infrastructure in the US include or fail to include climate change, see the report [Law and Policies that Address Equitable, Climate-Resilient Water and Sanitation](#) (Campbell-Ferrari et al. 2024).

11.1 LAWS SET STRUCTURAL STANDARDS TO ENSURE RELIABILITY OF SERVICES

Attribute description: Federal, state, and local governments adopt siting, design, and construction requirements and standards for rural water and wastewater services and infrastructure that explicitly address the impacts of climate change.

As infrastructure is updated, expanded, or rebuilt after a disaster, laws can be enacted to change existing rules so that it is built following more climate-resilient practices. Laws can also incentivize utilities to physically connect to other neighboring utilities or install infrastructure to maintain backup water supplies to reduce risks during drought or other climate-induced disasters. Building codes can legally require new construction to have flood and wildfire mitigation features and water augmentation plans or to use water-efficient fixtures, appliances, and landscaping. They can also require that older buildings be retrofitted with more efficient devices, helping to conserve water in the future when water availability is less dependable.

As droughts intensify due to climate change, water systems will become more challenged to serve sufficient, safe water to their communities (Pacific Institute and DigDeep 2024). This is especially true for small, rural water systems that are geographically isolated from a diversity of water sources or for whom the cost of constructing and maintaining back up sources and additional storage is a barrier. Some states like California, Texas, Colorado, Arizona, and Florida already require water systems to have a drought management or contingency plan to help prepare for droughts and water shortages. As part of these plans or as additional regulation, states can also adopt laws that encourage water systems to physically connect to backup water supplies and/or to have storage specifically for drought and other emergency situations. One legal approach to this can be laws that enable interties (physical, piped connections) with neighboring water systems. Sometimes laws are needed to remove existing regulations that inhibit interties.

While some states openly encourage interties and physical connections between water systems (e.g. Kentucky, California), other states have legal processes that inhibit or make creating physical connections or interties (and the agreements associated with them) onerous to the point of preventing them (Landes et al. 2021). This was the case in New Mexico until 2023. Due to a limited legal framework for regionalization, certain types of water and wastewater systems that wanted to formally consolidate and create a regional authority had to pass their own project-specific

legislation in the state legislature. Landes and co-authors argued that this made it extremely difficult for groups wanting to pursue regionalization to successfully complete it. In 2023, the state of New Mexico passed the Regional Water System Resiliency Act (SB 1). This Act created a legal framework for small water and wastewater systems to voluntarily form regional water authorities, giving them more flexibility in how they address challenges like water supply reliability (RCAC 2023).

There is limited regulation of decentralized infrastructure like household wells and septic systems. Most regulations governing household wells and septic systems focus on permitting, siting, and construction requirements, but these vary by state. These regulations can include rules governing where wells or septic systems are constructed, how they are constructed, whether permits are required, or whether inspections are required.

More work is needed to evaluate the ways that laws or official standards help ensure that decentralized water and sanitation infrastructure is protected from floods, droughts, and other climate disasters. The authors of this report are not aware of a national-scale study of these laws or standards. Therefore, it is not possible to compare approaches across states or to assess comprehensively whether there are laws that help siting, designing, and constructing wells and septic systems to be protected from climate disruptions. Some states, like Vermont, provide guidance for well testing after a flood event (Vermont Department of Health, n.d.). Other states, like Florida, have laws designed to help protect domestic well owners from losing access to groundwater, but these laws do not explicitly address climate change (Campbell-Ferrari et al. 2024). Despite the fact that approximately 53 million US residents rely on private wells that often experience contamination after flooding, it is difficult to find an example of a law anticipating the impacts of floods on wells (Phillis and Flesher 2022).

11.2 LAWS PROTECT RIGHTS, ALLOCATIONS, AND USES OF WATER FOR DOMESTIC PURPOSES

Attribute description: Water rights, laws, and policies are adaptive and flexible so that, during times of scarcity, sufficient, safe, physically accessible, acceptable, and affordable water is available for domestic use in rural communities.

At the core of this attribute is the human right to water and sanitation, especially for communities that have historically lacked adequate water rights or have been left out of water management decision making. Access to water and sanitation are not only necessary for human survival but also critical for climate resilience. Laws are needed so that frontline communities in rural areas have sufficient, safe, acceptable, physically accessible, and affordable water for drinking, sanitation, firefighting, cooling during extreme heat, and other domestic purposes (Campbell-Ferrari et al. 2024). Safeguarding this access will also help improve public health, protect the environment, and provide economic benefits to individuals and the broader economy.

Laws that prioritize available water resources for domestic purposes could become more imperative as climate change shifts precipitation patterns and reduces the availability of water in some geographies (Lall et al. 2018; Payton et al. 2023). There are examples of states with laws that both create automatic prioritization of domestic uses during droughts and authorize water managers to

address emergency water shortages. Together, these provisions can help protect domestic needs when there is insufficient water to meet every demand. In some states, there may be potential for conflict between water users during times of scarcity where laws prioritizing water uses are not clear, such as between domestic and agricultural uses. For example, in Kentucky agricultural water use is given the same protection as domestic water use, setting up a potential for conflict between the two uses if there is a water shortage (Campbell-Ferrari et al. 2024).

Groundwater is managed at the state level, resulting in a diversity of approaches across the 50 states. Groundwater laws give limited consideration to the impacts of climate change (Craig 2020; Eckstein et al. 2022). However, laws in Oregon and Kentucky allow for existing uses to be restricted during droughts. In Oregon, the Water Resources Commission has the authority to grant a temporary preference to water rights for human consumption and/or stock watering uses once a Drought Declaration has been made by the Governor for a county (Oregon Water Resources Department 2023). Another example is in Kentucky where, during a drought or emergency, water users' rights and permits can be temporarily restricted or reallocated to other users (Eckstein et al. 2022). This helps to ensure that water will be available to meet household needs during times of water scarcity.

Having explicit legal protections for municipal water use or domestic uses fulfilled by municipal suppliers helps to ensure that frontline communities will not lose access to water for drinking, cooking, and sanitation during droughts and other extreme events that become more frequent and intense under a changing climate. The law can ensure that water is allocated to and prioritized for municipal and domestic purposes.

11.3 THE LAW REQUIRES WATER AND WASTEWATER UTILITIES, AS WELL AS STATE AND LOCAL GOVERNMENTS, TO CONDUCT CLIMATE RESILIENCE PLANNING

Attribute description: The law requires rural water and wastewater systems and government agencies to adopt climate resilience plans to guide water resource management and asset management.

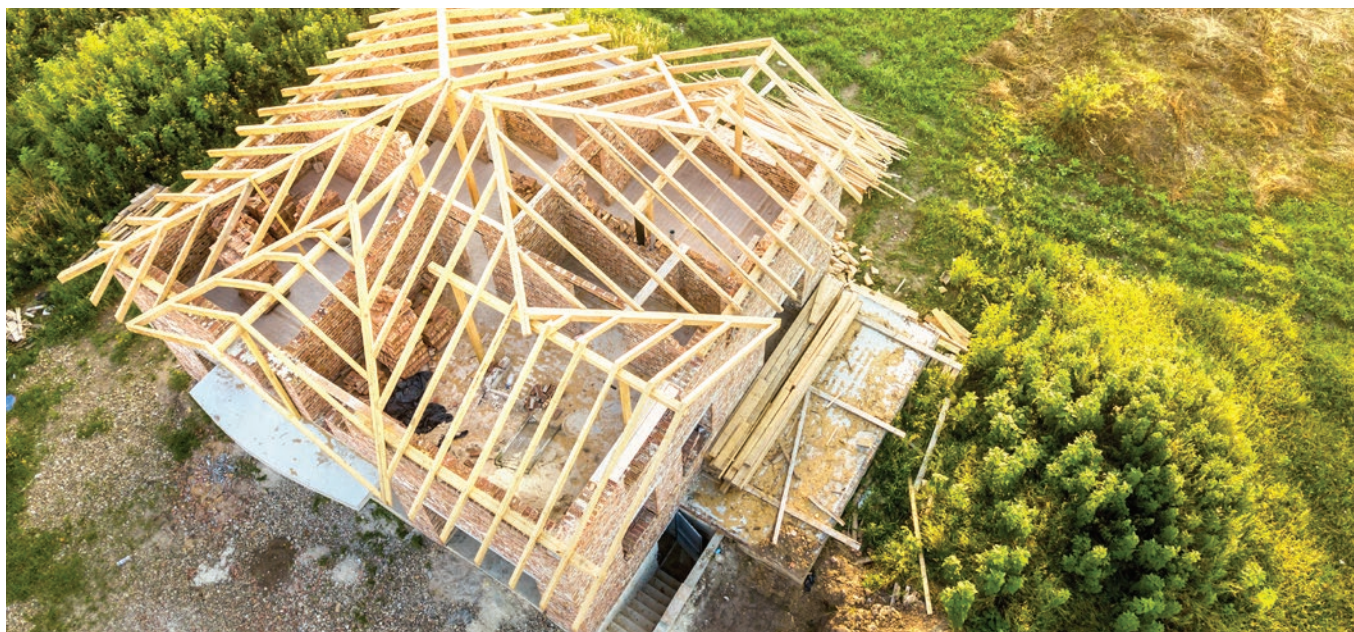
Climate resilience planning is essential for water and wastewater utilities and state and local governments working to prepare for and manage the impacts of climate change on water and wastewater services and infrastructure (see [Section 7](#)). Often smaller, rural water and wastewater systems lack the staff or the technical capacity to conduct robust assessments that enable them to prepare for and adapt to climate change. However, as described in [Section 7](#), these plans are needed to help rural water systems protect source water, gather community input, and improve financial sustainability. They also help to assess and respond to climate risks, coordinate with other sectors for disaster response, and monitor and evaluate their progress toward climate resilience goals. Laws can determine if and how climate resilience planning is done, who is responsible, and what resources governments must provide to ensure smaller systems are able to adopt climate resilience plans.

America's Water Infrastructure Act (AWIA), adopted in 2018, requires community water systems serving more than 3,300 people to conduct risk and resilience assessments, while excluding systems serving fewer than 3,300 people from this requirement. AWIA requires larger systems to assess risks from natural hazards to their infrastructure, including financial infrastructure, and to their operations and maintenance. However, the law never explicitly mentions climate change. The size exclusion also leaves out many small, rural water utilities, leaving a gap that some states have filled.

For example, S.B. 552 (2021), California's Drought Planning for Small Water Suppliers Act, sets requirements for small water systems and schools with their own water supply to develop water shortage contingency plans with specific drought elements (California Department of Water Resources 2022a). To address the capacity challenges created by these requirements, the act requires that county governments lead the drought and water shortage planning. To facilitate this role, the state has provided training for counties to learn about their new role, created resources like contingency plan templates, and established an interagency task force to facilitate better collaboration between stakeholders surrounding drought response. The state also set up the Small Community Drought Relief Program to provide small water systems with funding and technical assistance, which can be used for extending surface water intakes, water hauling, installing water tanks, and other measures (California Department of Water Resources 2022b; 2022a).

Laws can play a critical role in mandating climate resilience planning that safeguards households relying on decentralized water and sanitation systems. For instance, legislation can require state and local governments to assess climate-related risks to household water and wastewater infrastructure and develop appropriate response plans. This could include evaluating how climate change may affect groundwater levels and, in turn, the reliability of household wells. This helps to ensure that at-risk households are identified and protected from potential loss of water access.

Proactive climate resilience planning can help rural water systems and rural households retain access to water. It can also support state and local governments in planning for the resources and other support that might be needed by households to adapt to climate impacts.



11.4 LAWS REQUIRE CREATION, COLLECTION, AND PUBLICATION OF DATA AND INFORMATION

Attribute description: Laws across all jurisdictions create requirements to monitor and collect data and information critical to preparing rural water and sanitation services and infrastructure for climate change.

Relevant data and decision-support information are important for equitable, climate-resilient water and sanitation to assist with compliance and enforcement, to create transparency, and to facilitate public engagement (McNeeley et al. 2025). Credible, evidence-based information and data are critical for identifying climate change impacts to water and wastewater infrastructure and for monitoring changing conditions over time. By having information and data that are regularly collected and analyzed, utilities can (a) understand the challenges they face in operating and maintaining their infrastructure and providing safe and reliable services and (b) anticipate and respond to those impacts to reduce harm. This is important for the safety and reliability of water and sanitation services and to ensure compliance with legal requirements. Law is one of the few mechanisms that can require data and information collection and monitoring related to climate change impacts to water and sanitation services and infrastructure.

In the US, the SDWA and CWA are the main federal laws that guide what information large and small centralized water and wastewater systems must collect and report to the public, state regulators, and the US EPA. The SDWA sets national standards for the drinking water quality supplied by public water systems with more than 15 connections and, therefore, requires regulated water systems to monitor and report water quality parameters, like microorganisms and chemical contaminants (e.g., arsenic, lead, copper).

The goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters (Clean Water Act, 33 U.S.C. § 1251(a) (1972)). One way that the CWA allows for this goal to be achieved is to let states and Tribal governments establish programs to regulate discharges into streams, rivers, lakes, and oceans. For example, most states have created their own state-led National Pollutant Discharge Elimination Systems (NPDES) programs. NPDES programs establish technology-based municipal and industrial standards for pollution control and permits. Under the permits, regulated wastewater systems must monitor their discharge (i.e., effluent) and report on various parameters (e.g., chemical constituents, pathogens, and toxic substances). While these requirements are critical for protecting public health and the environment, neither the SDWA nor the CWA include monitoring or reporting requirements related to climate change. Nevertheless, under the CWA, states could implement new programs or update existing programs to address the impacts of climate change on water quality (River Network 2022).

Law is one of the few mechanisms that can require data and information collection and monitoring related to climate change impacts to water and sanitation services and infrastructure.

Decentralized water and sanitation systems are regulated at the state level if they are required to monitor water quality or functionality. In Maryland, for example, the Private Well Safety Act (2023) requires the Maryland Department of Environment adopt by December 2026 regulations with county-specific contaminants of concern and private well testing recommendations, including for manganese, radon, arsenic, mercury and other volatile compounds (Maryland Private Well Safety Act of 2023, SB 0483; Young, Hester, and Rosapepe 2023). The law also requires the Maryland Department of Environment create an accessible online database of well water quality test results (subject to funding), water quality testing every three years at rental properties served by private wells, and water quality testing during the sale of a home with a well. This law demonstrates one approach to improving the collection of information and monitoring of water quality in private wells. More frequent monitoring and greater transparency helps protect the health of the users of those wells as well as to track changes that could be caused by climate change.

11.5 LAWS APPROPRIATE AND EQUITABLY DISTRIBUTE FUNDING FOR WATER AND WASTEWATER SERVICES AND INFRASTRUCTURE

Attribute description: Federal, state, and local laws equitably appropriate and distribute financial resources to fund and finance the rehabilitation of existing and construction of new climate-resilient rural water and wastewater infrastructure.

Many water and wastewater systems in the US struggle to generate sufficient revenue through rates and other local sources to adequately maintain safe and reliable services. This is especially true for small, rural systems (Bostic et al. 2021; Feinstein et al. 2020). To pay for climate adaptation or resilience projects, like installing a new well or rehabilitating a wastewater treatment plant that was damaged by flooding, rural water and wastewater utilities need access to low- or no-cost loans or grants. Federal, state, and local laws can create new government funding programs as well as authorize funds for new and existing programs (see [Section 10](#) for more information on funding programs).

Federal laws, like the Bipartisan Infrastructure Law (2021) (BIL, also called the Infrastructure Investment and Jobs Act) and the Inflation Reduction Act (IRA) (2022), provided water and wastewater funding and financing programs with billions of dollars to address aging infrastructure, replace lead water pipes, support water-related climate resilience and safe and clean water projects, restore ecosystems, and support climate and hydrology science and data collection (The White House 2022; Gleick, Bielawski, and Cooley 2021). The new administration in 2025 has created uncertainty around the fate of many of the climate- and equity-related programs that were created or supported by the BIL and IRA, yet these are two clear examples of how federal laws can directly contribute to building more equitable and climate-resilient water and sanitation systems in rural and urban areas.

Loans and grants from government funding programs — such as the Drinking Water State Revolving Loan Funds (DWSRF) and Clean Water State Revolving Loan Funds (CWSRF) — are another funding source used by both large and small water and wastewater systems to pay for planning and infrastructure projects. The CWSRF was created in 1987 by the CWA (33 U.S.C. § 1383 (1987)). The Drinking Water State Revolving Fund (SRF) program was launched under the SDWA in 1996 (Pub.

L. No. 104-182, 110 Stat. 1613 (Act of Aug. 6, 1996)). The CWSRF and DWSRF have since primarily functioned as loan programs, whereby the recipients are responsible for paying loans back, which requires the financing costs to be recuperated from ratepayers.

How laws that appropriate and determine government funding are written can also dictate if funding is distributed equitably and if it is accessible to the communities who need it most. In 1996 when the SRF was established as part of the SDWA, Congress authorized states to use up to 30% of their DWSRF capitalization grants to provide additional assistance to disadvantaged communities as defined by the statute. This required states to make DWSRF funding available essentially as grants instead of loans, greatly reducing the financial barrier for drinking water systems serving communities with a high proportion of low-income customers.

State laws can be written to create funding specifically for rural water and sanitation systems, including decentralized systems. The National Conference of State Legislatures compiled a list of seven examples of state laws that created funding for small and rural water and wastewater systems (National Conference of State Legislatures 2022). For example, in 2021, the Florida state legislature passed Senate Bill 2500, designating \$25 million for a grant program to assist septic to sewer conversion and wastewater system upgrades for small communities. The grants were specifically designated for Rural Areas of Opportunity (Fla. State. 288.0650) and Fiscally Constrained Counties (Fla. Stat. 218.67(1)).

How laws that appropriate and determine government funding are written can also dictate if funding is distributed equitably and if it is accessible to the communities who need it most.

Loan programs can also be distributed directly to households, which is particularly helpful in rural communities where service provision is at the household level. The USDA Rural Decentralized Water Systems Grant Program provides funding to nonprofits. The nonprofits can then use the funding to create revolving loan funds or award subgrants to homeowners to increase access to household water and wastewater systems in rural areas. A loan up to \$15,000 can be used to construct, refurbish, or service household-level water wells and decentralized wastewater systems in rural areas with populations of 50,000 or less, Tribal lands, or colonias (USDA n.d.-d). This type of loan program is unique and responsive to the needs of rural communities. Laws are important in creating specific grant and loan programs for meeting water and wastewater needs in rural communities.

11.6 LAWS ARE ENFORCEABLE AND ENFORCED

Attribute description: Federal, state, and local laws create enforcement mechanisms for drinking water and sanitation systems serving rural communities to meet legal and regulatory standards and include consequences commensurate with noncompliance to reduce risk of harm from climate change impacts to water resources and systems.

Small centralized water and wastewater systems, those serving 10,000 people or fewer, experience greater challenges in maintaining and operating their systems and staying in compliance with legal and regulatory requirements (Feinstein et al. 2020). These challenges largely stem from financial constraints, technical and capacity limitations, and aging infrastructure (Rural Community Assistance Partnership 2020; US EPA 2011; US EPA 2015i). Climate change adds new and additional challenges for small, rural water and wastewater systems.

Decentralized water and wastewater systems and infrastructure are regulated at the state and local levels, not at the federal level. Most of these laws pertain to the construction of household wells and decentralized sanitation, such as laws that establish standards for siting and drilling wells. However, there are limited, if any, state or local requirements for ongoing oversight and management to ensure continued safety and reliability of decentralized infrastructure. This is true despite there being civil and criminal legal and/or regulatory consequences for failed septic systems that contribute to surface water pollution. This means that enforcement is largely focused on the construction and failure stages.

Decentralized water and wastewater systems and infrastructure are regulated at the state and local levels, not at the federal level.

In Maryland, enforcement of the state's well drilling rules is overseen by the State Board of Well Drillers, the Maryland Department of the Environment, and local health departments (Department of Legislative Services 2018). The State Board of Well Drillers receives complaints for alleged violations committed by a licensee and can suspend or revoke a license if the licensee fraudulently obtains or uses a license or is guilty of gross negligence or misconduct while operating (Department of Legislative Services 2018). In the period from 2013 to 2018, the Board received 64 notices of potential violations and suspended two licenses. This limited enforcement suggests that issues with well installation may go unaddressed and increase the risk of system failures. As climate change intensifies extreme weather events and groundwater availability, these risks could further threaten rural access to drinking water. To ensure that climate change impacts are anticipated and properly managed to protect public health, the law can establish greater requirements so that decentralized infrastructure is climate resilient.

11.7. LAW AND POLICY SUMMARY

For laws to help build more equitable, climate-resilient water and wastewater services and infrastructure in rural communities, they need to set structural standards to ensure reliability of services; protect rights, allocation, and uses of water for domestic purposes; require utilities, states, and local governments to conduct climate resilience planning; require the creation, collection, and publication of information; and appropriate and equitably distribute funding. These laws must furthermore be enforceable and be enforced.

The law currently takes a largely hands-off approach with decentralized water and sanitation infrastructure, in part because this infrastructure is located on private property. However, this approach minimizes oversight to the detriment of ensuring consistent provision of safe, reliable services over its lifetime, even as the climate changes.



12. Conclusion

Throughout the US climate change is complicating existing challenges in rural communities related to water quality, affordability, access, aging or nonexistent infrastructure, and disaster preparedness and recovery. Rural water and sanitation systems will be among those that experience climate change impacts first and worst. This is because many rural systems are overburdened and may also lack sufficient technological, financial, and management resources to address and prepare for climate impacts. Further, climate change impacts to rural water and sanitation systems may be disproportionately experienced by low-income households and communities, Indigenous communities, and communities of color, thereby deepening existing inequalities.

Despite the myriad barriers and challenges in the US, rural communities are finding innovative ways to achieve equitable, climate-resilient water and sanitation. This report compiles tangible, context-specific strategies developed by and for rural communities to make progress toward this goal.

Built infrastructure is being constructed and upgraded to provide more equitable, climate-resilient water and sanitation access to rural community members.

Technologies and innovations are being designed collaboratively with rural community members to enhance the climate resilience of water and sanitation systems in culturally sensitive ways. Natural infrastructure strategies are being developed to simultaneously enhance the climate resilience of water and sanitation systems and to equitably provide economic and cultural benefits for rural community members. Rural water managers and planners are developing locally tailored plans with community members to deliver equitable, climate-resilient water and sanitation access.

Rural communities are overcoming barriers to accessing the financial resources that they need for climate adaptation of water and sanitation or to recover and equitably 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, and Indigenous knowledges to ensure rural communities and people in positions of power and authority can understand, access, and use the data and information they need for decision making. The capacity of rural water and sanitation systems staff and decision makers is growing to better center the needs of rural community

Despite the myriad barriers and challenges in the US, rural communities are finding innovative ways to achieve equitable, climate-resilient water and sanitation.

members and to educate and support the water and sanitation sector workforce to equitably enhance climate resilience. In some places, laws and policies are enabling the construction and management of more equitable, climate-resilient rural water and sanitation systems.

We identified more than 130 strategies and approaches implemented in rural communities to advance equitable, climate-resilient water and sanitation (see Tables A1–A8 in the Appendix). While laudable progress has been made, there is a need for more. Importantly, there is no one-size fits all solution; rather, the solutions must be tailored to the needs and desires of local communities. Further, identifying and implementing these strategies and approaches will require collaboration between rural communities, community-based organizations, water resource managers, water and wastewater utilities, policy and law makers, and Tribal, federal, state, and local governments.

We identified more than 130 strategies and approaches implemented in rural communities to advance equitable, climate-resilient water and sanitation.

While this report draws on the large and growing body of knowledge on strategies for equitable and climate resilient water and sanitation systems in rural US communities, our research identified gaps that indicate a need for future research to support this goal. Our recommendations follow.

1. Assess the types of climate literacy programs, tools, and trainings that would be accessible to and usable by rural water and sanitation professionals.
2. Develop programs, resources, tools, and funding mechanisms to support the creation of water efficient technology incentive programs, the installation of onsite water and wastewater infrastructure, and other climate resilience measures in rural communities, particularly for low-income households.
3. Create policies so rural communities have equitable access and receive equitable benefits from climate-resilient infrastructure funding and climate disaster response and recovery funding.
4. Evaluate the climate resilience, scalability, and effectiveness of programs that connect rural households and communities to centralized water and/or wastewater systems.
5. Assess effective and locally tailored climate-resilient operation and maintenance of rural centralized and decentralized water and sanitation infrastructure.
6. Analyze the effectiveness of collaborative approaches between rural communities, water systems, nonprofits, and other organizations to plan for and manage cross-sector interdependencies to enhance climate resilience.
7. Evaluate the intersection of rural utility financial capability, household affordability, and climate resilience.
8. Evaluate the effectiveness of funding to help rural households install onsite water and wastewater systems to improve climate resilience

9. Evaluate how water utility assistance programs for rural households contribute to equitable climate resilience.
10. Assess the feasibility of natural infrastructure in rural areas for equitable, climate-resilient rural water and sanitation.

We hope that the strategies, tools, and case examples outlined in this report can support advancement toward this goal in many different rural communities. The report presents documented examples and resources on possible points of leverage to create innovative, place-based, and community-inclusive strategies for equitable, climate-resilient water and sanitation. Careful consideration will be needed to understand how to adapt strategies and approaches from one place to another. More attention is needed to better understand and support the needs and opportunities for rural 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, any solutions might fall short of achieving these goals. We present this report as a foundation of knowledge upon which to build practical solutions for the rural communities who need them the most.



Appendix: Tables of Identified Attributes, Strategies, and Approaches per Category

BUILT INFRASTRUCTURE STRATEGIES

TABLE A1. Built Infrastructure Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Rural communities have access to drinking water and sanitation infrastructure and services that allow them to perform basic tasks and maintain personal hygiene in their homes.	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 in rural areas.
	Create programs to connect rural 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 performs reliably under a wide range of climate conditions to deliver safe, sufficient, and acceptable water and sanitation for rural communities.	Create and utilize tools and frameworks for rural water and sanitation systems staff to evaluate the climate resilience of existing water and sanitation infrastructure.
	Improve rural water reliability through water reuse, water efficiency, 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.
	Update and/or elevate centralized and decentralized water and wastewater infrastructure to protect it from sea level rise and inland flooding.
	Adapt rural 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 rural community water stations and other infrastructure to protect them from damage and destruction.

Processes for siting, designing, and constructing climate-resilient water and sanitation infrastructure are inclusive and equitable to center rural community values and needs.	Create and utilize practical guidance for utilities and other groups involved in infrastructure projects that address equity and climate resilience.
	Incorporate direct input from rural communities when siting and designing climate-resilient water and sanitation.
The operations and maintenance (O&M) of water and sanitation build climate resilience and ensure equitable outcomes for rural communities.	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 so that rural 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 O&M tasks needed for improving climate resilience.
	Engage directly with rural communities by prioritizing O&M work that addresses long-standing inequities in service from racism, disinvestment, and marginalization.

TECHNOLOGY AND INNOVATION STRATEGIES

TABLE A2. Technology and Innovation Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Sustainable, climate-resilient rural 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.	Engage with stakeholders, paying special attention to local values and cultures, when designing and implementing rural water and sanitation technologies and innovations.
	Develop respectful partnerships between universities, technology companies, and rural communities to co-develop technologies tailored to community 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.
Water fixture upgrades, water-saving appliances, and other water-saving technologies are equitably installed to save water and reduce cost burden on utility bills of rural households.	Develop water efficiency programs tailored to low-income residents so that they benefit from cost-saving technologies.
	Partner with community-based organizations to build trust within rural communities and enhance participation in tailored low-income water efficiency programs.
	Leverage corporate investments to implement water and cost-saving technologies in rural communities, such as affordable housing complexes.

Sustainable water-use and sanitation technologies are implemented for large-scale water users and operations, like commercial and industrial users, and increase equity and climate resilience for rural communities.	Establish laws and policies that promote the large-scale adoption of water technologies, offering broad climate-resilience benefits for rural communities.
	Utilize existing support programs to scale up the implementation of innovations across sectors, such as university extension support programs for agricultural producers to install efficient irrigation technologies.
	Utilize water and wastewater technologies to close gaps in access to services after climate disruptions.
	Design and pilot large-scale water technologies and innovations collaboratively with nongovernmental organizations (NGOs) and technology companies.
New, innovative climate-resilient water technologies are tested and evaluated to help ensure dependability and safety for rural communities.	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 STRATEGIES

TABLE A3. Natural Infrastructure Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Governance, policy, legal, and financial constraints for natural infrastructure (NI) implementation are addressed and removed through context-specific practices to support equitable climate resilience in rural communities.	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 build NI project support and consensus.
	Use innovative and diverse funding sources appropriate to the local context.
Rural communities and equity are centered in NI planning for climate resilience.	Incorporate definitions and principles of equity and justice in NI projects.
	Use community-led decision making for NI planning and implementation.
	Incorporate transparency, trust building, and mutual learning in community engagement.
	Form partnerships with trusted individuals or organizations.
Displacement risks of rural NI projects are identified and addressed at the outset.	Utilize and adapt existing toolkits to identify local risk factors for displacement.
	Implement locally appropriate and feasible anti-gentrification and displacement policies and practices prior to project construction.
Context-specific approaches to the valuation of NI for equitable, climate-resilient rural water and sanitation are used in decision making.	Utilize comprehensive economic valuation methodologies that center climate resilience, human and ecological well-being, and benefits for multiple sectors and stakeholders.
	Use complementary tools to understand and communicate the benefits and tradeoffs of NI projects for rural communities.
	Incorporate nonmonetary valuations that center equity.

MANAGEMENT AND PLANNING STRATEGIES

TABLE A4. Management and Planning Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Source water protections are part of water and sanitation planning and management to increase rural community resilience to climate change.	Develop locally tailored source water protection plans by leveraging existing support programs that connect community members and local organizations in collaborative, proactive efforts to safeguard water quality.
	Include technologies and innovations, such as managed aquifer recharge, in plans and programs to enhance source water security.
	Collaborate with rural 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.
Equitable involvement and empowerment of community members in planning and management are achieved by centering rural community priorities.	Begin with a visioning stage to incorporate rural community insights into climate-resilient water and sanitation planning from the outset.
	Utilize resources and support from community-based organizations to improve the representation of rural communities in climate adaptation and water and sanitation planning.
	Foster collaborative research partnerships that provide a boundary function, connecting rural communities with regional and national planning efforts while developing locally tailored resources for self-reliance.
	Take proactive measures to encourage participation, such as stipends, to empower rural community members to meaningfully engage in management and planning processes.
The financial health of rural utilities and communities is supported by proactive, long-term planning and management strategies that result in accessible, affordable, and climate-resilient water and sanitation.	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 rural communities.

There is regular planning and management for climate disasters and inequitable climate disruptions to rural water and sanitation systems.	Create emergency response plans that address climate disruptions and prioritize equitable access to water and sanitation for rural communities.
	Develop and utilize local tools on climate disruptions to rural water and sanitation systems to inform residents, encourage participation in planning, and bolster community preparedness.
	Include community input in risk assessments to inform climate-preparedness plans and programs that equitably address the needs of those most affected.
	Participate in training and workshops, focused on equity, to prepare water and sanitation systems for climate disruptions.
	Incorporate a diverse range of water sources into programs and plans to enhance redundancy and resilience, especially for rural communities.
Equitable and climate-resilient management and planning efforts are coordinated across sectors, departments, agencies, plans, and different scales of government in rural communities.	Align management and planning processes strategically, using integrated and collaborative frameworks.
	Include interagency and cross-sector working groups in climate disaster response programs and plans to clarify roles, establish coordinated technical assistance programs for rural communities, and incorporate equitable community input into plans.
	Integrate coordinated frameworks between government agencies and nonprofits to address and manage cross-sector, complex water and sanitation challenges together.
	Participate in specialized training and exercises to learn how to address climate impacts on rural communities equitably and collaboratively across sectors.
Water planners and managers continually monitor and evaluate water and sanitation effectiveness to achieve equitable and climate-resilient outcomes for rural communities.	Involve community members and community-based organizations in the design and implementation of monitoring frameworks to promote inclusive, attainable, and locally informed processes.
	Use equity-focused indicators to track climate resilience outcomes of water and sanitation plans and programs effectively across rural communities.
	Allocate specific funding for monitoring and evaluation in climate adaptation planning efforts so that small and underresourced communities have the financial capacity to monitor and evaluate climate, water, and sanitation initiatives.
	Apply monitoring and evaluation to both new initiatives and existing practices to comprehensively address systemic inequities and enhance accountability.

FUNDING AND FINANCING STRATEGIES

TABLE A5. Funding and Financing Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Climate-resilient infrastructure projects for water and sanitation systems serving rural communities and households can obtain and sustain funding and/or financing.	Increase the amount of funding available through federal and state programs, including the Clean Water State Revolving Fund and Drinking Water State Revolving Fund, that can be used to build and adapt climate-resilient rural water and sanitation infrastructure.
	Ensure that funding and financing are accessible and do not have barriers for rural communities to identify, apply for, and use to build and adapt climate-resilient water and sanitation infrastructure.
	Enact policies so that rural communities are receiving an equitable amount of benefits from climate and infrastructure funding.
	Implement technical assistance programs to address barriers experienced by rural communities in identifying, applying for, and using funding for climate-resilient water and sanitation infrastructure.
	Offer programs to help construct climate-resilient, onsite water and sanitation infrastructure and/or to connect rural homes and communities with decentralized infrastructure to more climate-robust centralized systems.
Climate-resilient operations and maintenance (O&M) for water and sanitation systems in rural communities have adequate and sustainable funding and assistance.	Create and fund grant programs that explicitly name climate resilience and O&M as funding priorities for water and sanitation systems.
	Work with free technical assistance providers with climate knowledge and expertise to reduce the financial burden of O&M.
	Offer programs that provide grants or assistance for income-qualified households to test well water, repair wells or septic systems, or train onsite system owners on O&M.
	Provide free training and other resources that inform owners on well and septic system operations and maintenance to enhance climate resilience.

Rural 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.	Increase funding available through federal community preparedness and climate hazard mitigation programs for protect-in-place, managed retreat, and relocation, and consolidate funding to improve access to these programs for rural communities.
	Dedicate funds for declared emergencies in rural areas and simplify and expedite the approval process so funds are delivered quickly.
	Prevent climate disaster response and recovery efforts from exacerbating or increasing wealth inequality.
	Fill gaps in government aid with local efforts by grassroots coalitions and NGOs to create local financing options and climate disaster recovery.
	Designate funds for rural households to repair damage caused by disasters, including for repairs to wells and septic systems.
	Expand eligibility for federal flood insurance programs to cover all rural, Tribal, and currently unmapped households and communities.
Alternative approaches such as nature-based solutions (NBS), green infrastructure (GI), water efficiency, and water reuse have sustainable, adequate funding sources to support climate-resilient water and sanitation in rural communities.	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 rural communities to identify, apply for, and use the assistance.
	Enact policies so that rural communities are receiving an equitable amount of benefits from funding for alternative approaches.
	Offer programs to incentivize or pay for measures that enhance climate resilience of onsite water and sanitation in households in rural communities.
Rural 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.	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 so that 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.
	Create and fund programs to help rural households find leaks and replace inefficient fixtures and appliances to help save on their water, wastewater, and energy bills and support climate resilience.

KNOWLEDGE AND INFORMATION STRATEGIES

TABLE A6. Knowledge and Information Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
Water, climate, and other relevant data are at the appropriate temporal and spatial scales and readily accessible to decision makers, water managers, and rural 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 trusted support and expertise to increase capacity and overcome technical, legal, and policy barriers.
Climate data and projections are used with the inclusion of rural communities to inform water and sanitation and water resources risk assessments, planning, management, and development.	Use an end-to-end co-production approach in assessing climate risks to include rural 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.

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.	Ensure that local experts and knowledge holders 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 rural communities.
The needs and perspectives of rural communities are centered in data and information collection, which is shared openly and in culturally appropriate formats and languages that are accessible to rural communities.	Present a positive vision for the future and emphasize ongoing progress, rather than relying on fear appeals.
	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.
	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.
	Use credible sources when incorporating climate change into rural water and sanitation initiatives to provide clarity and slow the spread of misinformation.

CAPACITY BUILDING STRATEGIES

TABLE A7. Capacity Building Strategies

ATTRIBUTES	EXAMPLE STRATEGIES AND APPROACHES
The water and sanitation workforce in rural communities is robust, climate-literate, and representative of the communities being served.	Take advantage of climate adaptation training, programs, and tools to increase climate literacy in the water and sanitation workforce.
	Provide opportunities for recognition and networking for upcoming utility leaders, especially those from underrepresented groups.
	Educate students and other career-ready individuals about the water and sanitation sector and recruit the next generation of water and wastewater utility professionals.
Rural communities are supported and have sufficient capacity for inclusive, equitable, and culturally appropriate participation in climate, water, and sanitation decision making.	Build trust between rural communities and water and wastewater utilities serving them by promoting transparency, inclusivity, and community engagement.
	Co-produce information and co-develop strategies and educational tools for climate-resilient water and sanitation with rural communities using community-based participatory research and an asset-based approach.
	Develop partnerships between rural community members, community-based organizations, and other nongovernmental organizations to advance community-driven water and sanitation policies.
People managing water and sanitation systems have the ongoing capacity to coordinate with people in sectors with whom they are interdependent for climate resilience.	Leverage existing tools and resources, such as the 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.

Water managers are empowered with the technical, managerial, and financial (TMF) and leadership skills to equitably create, adapt, and maintain climate-resilient water and sanitation systems for their communities.	Require TMF trainings for water system board members.
	Establish formal and informal social networks among underserved systems to share information and resources to help overcome capacity challenges and prepare for climate impacts.
	Consider consolidation and regionalization of small, underresourced water and wastewater systems to enhance capacity.
	Take advantage of leadership and TMF training and assistance programs to build capacity to advance climate-resilient strategies.

LAW AND POLICY ATTRIBUTES⁴⁷

TABLE A8. Law and Policy Attributes

ATTRIBUTES	ATTRIBUTE DESCRIPTION
Laws set structural standards for reliability of services.	Federal, Tribal, state, and local governments adopt siting, design, and construction requirements and standards for rural water and wastewater services and infrastructure that explicitly address the impacts of climate change.
Laws protect rights, allocations, and uses of water for domestic purposes.	Water rights, laws, and policies are adaptive and flexible so that during times of scarcity, sufficient, safe, physically accessible, acceptable, and affordable water is available for domestic use in rural communities.
The law requires water and wastewater utilities as well as state and local governments to conduct climate resilience planning.	The law requires rural water and wastewater systems and government agencies to adopt climate resilience plans to guide water resource management and asset management.

⁴⁷ Note that the Law and Policy table includes the attributes identified in Section 11, as strategies will be shared in a forthcoming report.

Laws require creation, collection, and publication of data and information.	Laws across all jurisdictions create requirements to monitor and collect data and information critical to preparing rural water and sanitation services and infrastructure for climate change.
Laws appropriate and equitably distribute funding for water and wastewater services and infrastructure.	Federal, state, and local laws equitably appropriate and distribute financial resources to fund and finance the rehabilitation of existing and construction of new climate-resilient rural water and wastewater infrastructure.
Laws are enforceable and enforced.	Federal, state, and local laws create enforcement mechanisms for drinking water and sanitation systems serving rural communities to meet legal and regulatory standards and include consequences commensurate with noncompliance to reduce risk of harm from climate change impacts to water resources and systems.



References

- 350 New Mexico. n.d. “Climate Disinformation Resources.” 350 New Mexico. Accessed April 22, 2025. <https://350newmexico.org/climate-disinformation-resources/>.
- 1854 Treaty Authority. 2017. “The Right to Hunt and Fish Therein: Understanding Chippewa Treaty Rights in Minnesota’s 1854 Ceded Territory.” <https://www.1854treatyauthority.org/images/ToHuntandFish.updated2020.pdf>.
- ACT. 2024. “Natural Solutions Initiative: Nature-Based Solutions Regulatory Mechanisms Toolkit.” Action on Climate Team, Simon Fraser University. https://www.sfu.ca/content/sfu/act/reports/regulatory-mechanisms-toolkit/_jcr_content/main_content/download/file.res/NbS%20Regulatory%20Mechanisms%20Toolkit.pdf.
- Administration for Children and Families. 2024. “LIHWAP Implementation and Impact Report.” 2024. <https://acfhhs.foleon.com/lihwap/impact-report/in-partnership-with-utilities>.
- Alabama Cooperative Extension System. n.d. “Alabama Water Watch.” Accessed April 22, 2025. <https://aaes.auburn.edu/alabamawaterwatch/>.
- Alabama Legislative Services Agency. 1967. *The Use Classification System. Department of Environmental Management Water Division - Water Quality Program Administrative Code*. Vol. Rule 335-6-11-.01. <https://admincode.legislature.state.al.us/administrative-code/335-6-11-.01>.
- Alaska Department of Commerce. 2024. “Newtok Planning Group.” Department of Commerce, Community, and Economic Development, Division of Community and Regional Affairs. 2024. <https://www.commerce.alaska.gov/web/dcra/planninglandmanagement/newtokplanninggroup.aspx>.
- Alaska Department of Environmental Conservation. 2020. “The Portable Alternative Sanitation System (PASS).” <https://dec.alaska.gov/water/water-sewer-challenge/resources/similar-efforts/>.
- Alaska Native Tribal Health Consortium. 2017. “Portable Alternative Sanitation System: Final Report, Kivalina, Alaska.” <https://anthc.org/wp-content/uploads/2025/05/Kivalina-Report-E-Version.pdf>.

- _____. 2024. “The Unmet Needs of Environmentally Threatened Alaska Native Villages: Assessment and Recommendations.” https://anthc.org/wp-content/uploads/2025/04/Unmet_Needs_Report_22JAN24-1.pdf.
- Albright, Elizabeth A., Catherine Coleman Flowers, Randall A. Kramer, and Erika S. Weinthal. 2024. “Failing Septic Systems in Lowndes County, Alabama: Citizen Participation, Science, and Community Knowledge.” *Local Environment* 29 (2): 135–42. <https://doi.org/10.1080/13549839.2023.2267066>.
- Allaire, Maura, Haowei Wu, and Upmanu Lall. 2018. “National Trends in Drinking Water Quality Violations.” *Proceedings of the National Academy of Sciences* 115 (9): 2078–83. <https://doi.org/10.1073/pnas.1719805115>.
- Amanambu, Amobichukwu C., Omon A. Obarein, Joann Mossa, Lanhai Li, Shamusideen S. Ayeni, Olalekan Balogun, Abiola Oyebamiji, and Friday U. Ochege. 2020. “Groundwater System and Climate Change: Present Status and Future Considerations.” *Journal of Hydrology* 589 (October). <https://doi.org/10.1016/j.jhydrol.2020.125163>.
- American Flood Coalition. n.d. “Flood Funding Finder.” American Flood Coalition. Accessed April 3, 2025. <https://floodcoalition.org/fundingfinder/>.
- American Psychological Association. n.d. “Misinformation and Disinformation.” <https://www.apa.org/topics/journalism-facts/misinformation-disinformation>. Accessed March 28, 2025.
- American Red Cross. 2024. “Disaster Relief.” 2024. <https://www.redcross.org/about-us/our-work/disaster-relief.html>.
- American Society of Civil Engineers. 2021a. “A Comprehensive Assessment of America’s Infrastructure.” American Society of Civil Engineers. https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.
- _____. 2021b. “Drinking Water Report Card.” American Society of Civil Engineers. <https://infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-2021.pdf>.
- _____. 2024. “ASCE’s 2025 Infrastructure Report Card.” <https://infrastructurereportcard.org/>.
- _____. 2025. “A Comprehensive Assessment of America’s Infrastructure: 2025 Report Card for America’s Infrastructure.” <https://infrastructurereportcard.org/wp-content/uploads/2025/03/Full-Report-2025-Natl-IRC-WEB.pdf>.
- American Water Works Association. 2008. “Economic Benefits of Forming and Participating in a Water/Wastewater Agency Response Network (WARN).”
- _____. 2018. “Source Water Protection Justification.” <https://wvawwa.com/wp-content/uploads/2019/06/source-water-protection-justification-toolkit-awwa.pdf>.

- _____. 2024. “Water/Wastewater Agency Response Network.” Resource Topics. 2024. <https://www.awwa.org/Resources-Tools/Resource-Topics/Water-Wastewater-Agency-Response-Network>.
- _____. n.d. “Exemplary Source Water Protection Award.” *American Water Works Association* (blog). Accessed April 23, 2025. <https://www.awwa.org/award/exemplary-source-water-protection-award/>.
- Anderies, John, Marco Janssen, and Elinor Ostrom. 2004. “A Framework to Analyze the Robustness of Social-Ecological Systems from an Institutional Perspective.” *Ecology and Society* 9 (1). <https://doi.org/10.5751/ES-00610-090118>.
- Anderson, Rebecca, and Shannon McNeeley. 2025. “The Growing Threat of Catastrophic Flooding in Rural America.” *Pacific Institute* (blog). February 27, 2025. <https://pacinst.org/the-growing-threat-of-catastrophic-flooding-in-rural-america/>.
- Anguelovski, Isabelle, Linda Shi, Eric Chu, Daniel Gallagher, Kian Goh, Zachary Lamb, Kara Reeve, and Hannah Teicher. 2016. “Equity Impacts of Urban Land Use Planning for Climate Adaptation: Critical Perspectives from the Global North and South.” *Journal of Planning Education and Research* 36 (3): 333–48. <https://doi.org/10.1177/0739456X16645166>.
- Appalachian Community Technical Assistance and Training. n.d. “Water WORCs in Appalachia.” Accessed April 18, 2025. <https://actat.wvu.edu/water-worcs>.
- Arizona Department of Environmental Quality. 2025. “Arizona Rural Water Infrastructure Committee.” April 15, 2025. <https://www.azdeq.gov/RWIC>.
- Arizona State University. n.d.-a. “AZ CuRVE.” Accessed April 22, 2025. <https://curve.dtn.asu.edu/>.
- _____. n.d.-b. “Rural Groundwater Resilience Toolkit.” Arizona Water Innovation Initiative, Impact Water - Arizona. Accessed March 3, 2025. <https://azwaterinnovation.asu.edu/rural-groundwater-resilience-toolkit>.
- _____. n.d.-c. “Rural Groundwater Resilience Workshops.” Arizona Water Innovation Initiative. Accessed April 22, 2025. <https://azwaterinnovation.asu.edu/rural-groundwater-resilience-workshops>.
- _____. n.d.-d. “The ASU Colorado River Visualization Enterprise.” Morrison Institute for Public Policy. Accessed March 3, 2025. <https://morrisoninstitute.asu.edu/tools/asu-curve-project>.
- Arizona State University Julie Anne Wrigley Global Futures Laboratory. n.d. “Water Narratives.” Narrative Storytelling Initiative. Accessed April 22, 2025. <https://www.narrativestorytelling.org/water-narratives>.
- ARUP, The Rockefeller Foundation, The Resilience Shift, and SIWI. 2019. “The City Water Resilience Approach.” ARUP. <https://www.arup.com/insights/the-city-water-resilience-approach/>.

- Atwater, Will. 2024. "Wastewater Treatment in a Box: Technology, Engineers Help Spruce Pine Fast-Track Recovery from Hurricane Helene." North Carolina Health News. November 26, 2024. <http://www.northcarolinahealthnews.org/2024/11/26/wastewater-treatment-in-a-box-technology-engineers-help-spruce-pine-fast-track-recovery-from-hurricane-helene/>.
- Balaji, Mala. 2023. "The Maladaptation Paradox: Unintended Consequences of Climate Solutions." Citizen Consumer and Civic Action Group. November 29, 2023. <https://www.cag.org.in/blogs/maladaptation-paradox-unintended-consequences-climate-solutions>.
- Balazs, Carolina L., and Mark Lubell. 2014. "Social Learning in an Environmental Justice Context: A Case Study of Integrated Regional Water Management." *Water Policy* 16 (S2): 97–120. <https://doi.org/10.2166/wp.2014.101>.
- Bassi, Andrea M, Liesbeth Casier, Georg Pallaske, Oshani Perera, and Ronja Bechau. 2020. "Sustainable Asset Valuation (SAVi) of Senegal's Saloum Delta." International Institute for Sustainable Development. <https://www.iisd.org/system/files/2020-08/savi-saloum-delta-senegal.pdf>.
- Becker, Rachel. 2020. "Unsafe to Drink: Wildfires Threaten Rural Towns with Tainted Water." *CalMatters*, October 5, 2020, sec. Environment. <http://calmatters.org/environment/2020/10/california-wildfires-unsafe-drinking-water/>.
- Bennett, Genevieve, and Franziska Ruef. 2016. "State of Watershed Investment 2016." Forest Trends. <https://www.forest-trends.org/publications/alliances-for-green-infrastructure/>.
- Berkes, Fikret. 2012. *Sacred Ecology*. 3rd ed. New York: Routledge. <https://doi.org/10.4324/9780203123843>.
- Berni, M., A. Rizzo, A. Menin, L. Bittini, E. Pacchierotti, R. Duina, and F. Masi. 2022. "Start Park Project: Co-Designing Green-Blue Infrastructures to Build Resilient Communities to Climate Change." In *Enhancing Environmental Education Through Nature-Based Solutions*, edited by Clara Vasconcelos and Cristina S. C. Calheiros, 4:231–47. Integrated Science. Springer International Publishing. https://doi.org/10.1007/978-3-030-91843-9_15.
- Bertana, Amanda, Brett Clark, Tabitha M. Benney, and Cameron Quackenbush. 2022. "Beyond Maladaptation: Structural Barriers to Successful Adaptation." *Environmental Sociology* 8 (4): 448–58. <https://doi.org/10.1080/23251042.2022.2068224>.
- Bertule, Maija, Lars Rosendahl Appelquist, Jason Spensley, Sara Laerke Meltofte Traerup, and Prakriti Naswa. 2017. "Climate Change Adaptation Technologies for Water: A Practitioners Guide to Adaptation Technologies for Increased Water Sector Resilience." UNEP DTU Partnership. https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/water_adaptation_technologies_0.pdf.
- Biagini, Bonizella, Rosina Bierbaum, Missy Stults, Saliha Dobardzic, and Shannon McNeeley. 2014. "A Typology of Adaptation Actions: A Global Look at Climate Adaptation Actions

- Financed through the Global Environment Facility.” *Global Environmental Change* 25 (March):97–108. <https://doi.org/10.1016/j.gloenvcha.2014.01.003>.
- Bisson, Peter A., Robert E. Bilgy, Mason D. Bryant, Andrew C. Dolloff, Glenn B. Grette, Robert A. House, Michael L. Murphy, Victor K. Koski, and James R. Sedell. 1987. “Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future.” In *Streamside Management: Forestry and Fishery Interactions*, 143–90. Seattle, Washington. <https://andrewsforest.oregonstate.edu/publications/1316>.
- Bladon, Kevin D., Monica B. Emelko, Uldis Silins, and Micheal Stone. 2014. “Wildfire and the Future of Water Supply.” *Environmental Science & Technology* 48 (16): 8936–43. <https://doi.org/10.1021/es500130g>.
- Boelee, Eline, Jan Janse, Antoine Le Gal, Marcel Kok, Rob Alkemade, and Willem Ligtoet. 2017. “Overcoming Water Challenges through Nature-Based Solutions.” *Water Policy* 19 (5): 820–36. <https://doi.org/10.2166/wp.2017.105>.
- Bostic, Darcy, Walker Grimshaw, Michael Cohen, Laura Landes, Nathan Ohle, Ted Stiger, Glenn Barnes, and Ari Newmann. 2021. “Customer Debt and Lost Revenue: The Financial Impacts of COVID-19 on Small Community Water Systems.” Oakland, California: Pacific Institute. https://pacinst.org/publication/COVID19_impacts_small_community_water_systems.
- Bradley, Sean. 2023. “CLEVER Cities: Building Urban Resilience Through Community-Led Decision Making.” Earth.Org. July 31, 2023. <https://earth.org/clever-cities-building-resilience-through-community-led-decision-making/>.
- Braveman, Paula A., Elaine Arkin, Dwayne Proctor, Tina Kauh, and Nicole Holm. 2022. “Systemic And Structural Racism: Definitions, Examples, Health Damages, And Approaches To Dismantling.” *Health Affairs* 41 (2): 171–78. <https://doi.org/10.1377/hlthaff.2021.01394>.
- Brill, Gregg, Deborah Carlin, Shannon McNeeley, and Delilah Griswold. 2022. “Stakeholder Engagement Guide for Nature-Based Solutions.” Oakland, California: United Nations CEO Water Mandate and Pacific Institute. <https://pacinst.org/publication/stakeholder-engagement-guide-for-nature-based-solutions/>.
- Brill, Gregg, Deorah Carlin, Cora Kammeyer, Hannah Baleta, Kari Vigerstøl, Naabia Ofosu-Amaah, Michael Matosich, et al. 2023. “Benefit Accounting of Nature-Based Solutions for Watersheds Guide Version 2.” Pacific Institute. <https://pacinst.org/publication/benefit-accounting-nbs-guide-2/>.
- Brown, Joe, Charisma S Acey, Carmen Anthonj, Dani J Barrington, Cara D Beal, Drew Capone, Oliver Cumming, et al. 2023. “The Effects of Racism, Social Exclusion, and Discrimination on Achieving Universal Safe Water and Sanitation in High-Income Countries.” *The Lancet Global Health* 11 (4): e606–14. [https://doi.org/10.1016/S2214-109X\(23\)00006-2](https://doi.org/10.1016/S2214-109X(23)00006-2).
- Brubaker, Michael Y., Jacob N. Bell, James E. Berner, and John A. Warren. 2011. “Climate Change Health Assessment: A Novel Approach for Alaska Native Communities.”

- International Journal of Circumpolar Health* 70 (3): 266–73.
<https://doi.org/10.3402/ijch.v70i3.17820>.
- Bucci, Sarah. 2024. “Just Infrastructure: Lessons on Water Infrastructure Storytelling.” The Water Hub. December 18, 2024. <https://waterhub.org/just-infrastructure-debrief/>.
- Bureau of Indian Affairs. 2024. “FY24 Funding to Support Tribal Climate Resilience.” Request for Proposals (RFP). Office of Trust Services.
https://www.bia.gov/sites/default/files/media_document/bia_tcr_2024_annual_awards_program_rfp.pdf.
- _____. n.d. “Tribal Community Resilience Annual Awards Program.” Accessed April 18, 2025.
<https://www.bia.gov/service/tcr-annual-awards-program>.
- Cajete, Gregory. 2000. *Native Science: Natural Laws of Interdependence*. Santa Fe, N.M.: Clear Light Publishers. <http://archive.org/details/nativesciencenat0001caje>.
- Calabretta, Sion, Maureen Cunningham, and Sridhar Vedachalam. 2022. “Investing in America’s Onsite Wastewater Treatment Systems for Equity and Sustainability.” Environmental Policy Innovation Center.
https://static1.squarespace.com/static/611cc20b78b5f677dad664ab/t/62e7bcf56ab0635d9c1ecf0c/1659354397043/FINAL_EPIC_SepticFinancingReport_2022.pdf.
- California Department of Water Resources. 2022a. *SB 552 - County Drought Plan Requirements for State Small Water Systems*.
- _____. 2022b. “Small Community Drought Relief.” 2022. <https://water.ca.gov/Water-Basics/Drought/Drought-Funding/Small-Community-Drought-Relief>.
- _____. 2023. “Status of 2020 Agricultural Water Management Plans and Implementation of Efficient Water Management Practices Report.” <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency/Files/Status-of-2020-AWMPs-and-Implementation-of-EWMPs-Report-to-Legislature.pdf>.
- _____. 2024. “Agricultural Water Use Efficiency.” CA.Gov. December 19, 2024.
<https://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency>.
- _____. n.d.-a. “Integrated Regional Water Management.” CA.Gov. Accessed February 12, 2025.
<https://water.ca.gov/Programs/Integrated-Regional-Water-Management>.
- _____. n.d.-b. “Water Shortage Vulnerability Scoring and Tool.” CA.Gov. Accessed April 21, 2025. <https://water.ca.gov/Programs/Water-Use-And-Efficiency/SB-552/SB-552-Tool>.
- California Environmental Protection Agency. 2021. “Achieving the Human Right to Water in California.” CA EPA Office of Environmental Health Hazard Assessment.
<https://oehha.ca.gov/media/downloads/water/report/hrtwachievinghrtw2021f.pdf>.

- California Public Utilities Commission. n.d. “Energy Savings Assistance.” Energy Savings Assistance. Accessed December 11, 2024. <https://www.cpuc.ca.gov/esap/>.
- California State Water Resources Control Board. 2024. “2024 Drinking Water Needs Assessment.” California Water Boards. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2024/2024-needs-assessment.pdf.
- _____. n.d. “SAFER Drinking Water.” Accessed April 18, 2025. <https://www.waterboards.ca.gov/safer/>.
- Campbell-Ferrari, Alexandra, Shannon McNeeley, Morgan Shimabuku, and Luke Wilson. 2024. “Law and Policies That Address Water and Sanitation and Climate Change.” Water, Sanitation, and Climate Change in the US Series, Part 2. Oakland, CA: Pacific Institute. <https://pacinst.org/publication/law-and-policies-that-address-equitable-water-sanitation-and-climate-change/>.
- Cannon, Emily. 2024. “Investing in Wastewater Infrastructure Is Key to Preserving Smith Island, Maryland.” Success Stories, Rural Development. April 22, 2024. <https://www.rd.usda.gov/newsroom/success-stories/investing-wastewater-infrastructure-key-preserving-smith-island-maryland>.
- Canon, Gabrielle. 2025. “California Tribes Celebrate Historic Dam Removal: ‘More Successful than We Ever Imagined.’” *The Guardian*, January 3, 2025, sec. US news. <https://www.theguardian.com/us-news/2025/jan/03/california-klamath-dam-removal>.
- Cash, David W., William C. Clark, Frank Alcock, Nancy Dickson, Noelle Eckley, and Jill Jäger. 2003. “Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making.” *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.372280>.
- Cash, David W., and Susanne C Moser. 2000. “Linking Global and Local Scales: Designing Dynamic Assessment and Management Processes.” *Global Environmental Change* 10 (2): 109–20. [https://doi.org/10.1016/S0959-3780\(00\)00017-0](https://doi.org/10.1016/S0959-3780(00)00017-0).
- Catalytic Communities. n.d. “Community Mapping through Transect Walks.” *Catalytic Communities* (blog). Accessed April 22, 2025. <https://catcomm.org/transect-walk/>.
- CDC Foundation. n.d. “Together Our Impact Is Greater.” Accessed May 29, 2025. <https://www.cdcfoundation.org/>.
- Center for Disease Control. 2024. “Benzene.” Chemical Emergencies. September 6, 2024. <https://www.cdc.gov/chemical-emergencies/chemical-fact-sheets/benzene.html>.
- CEO Water Mandate. 2024. “Water Resilience Assessment Framework.” Ceowatermandate.Org. 2024. <https://ceowatermandate.org/resilience-assessment-framework/>.
- _____. n.d. “NBS Benefits Explorer.” Accessed February 14, 2025. <https://nbsbenefitsexplorer.net/tool>.

- Chapin, F Stuart, Corrine N Knapp, Todd J Brinkman, Robin Bronen, and Patricia Cochran. 2016. "Community-Empowered Adaptation for Self-Reliance." *Current Opinion in Environmental Sustainability*, Sustainability science, 19 (April):67–75. <https://doi.org/10.1016/j.cosust.2015.12.008>.
- Checker, Melissa. 2011. "Wiped Out by the 'Greenwave': Environmental Gentrification and the Paradoxical Politics of Urban Sustainability." *City & Society* 23 (2): 210–29. <https://doi.org/10.1111/j.1548-744X.2011.01063.x>.
- Chenkin, Barry. 2025. "Rainwater Harvesting In Rural Areas." Aquabarrel. 2025. <https://www.aquabarrel.com/rainwater-harvesting-rural-areas>.
- Chew, Schuyler, and Karletta Chief. 2023. "Community-Engaged Participatory Climate Research with the Pyramid Lake Paiute Tribe." *Ecology and Society* 28 (1). <https://doi.org/10.5751/ES-13725-280116>.
- Chief, Karletta, Alison Meadow, and Kyle Whyte. 2016. "Engaging Southwestern Tribes in Sustainable Water Resources Topics and Management." *Water* 8 (8): 350. <https://doi.org/10.3390/w8080350>.
- Chow, Alex T., Kuo-Pei Tsai, Timothy S. Fegel, Derek N. Pierson, and Charles C. Rhoades. 2019. "Lasting Effects of Wildfire on Disinfection By-Product Formation in Forest Catchments." *Journal of Environmental Quality* 48 (6): 1826–34. <https://doi.org/10.2134/jeq2019.04.0172>.
- Christiansen, L., A. Olhoff, and S.L.M. Traerup. 2011. "Technologies for Adaptation - Perspectives and Practical Experiences." Technology Transfer Perspectives Series. Danmarks Tekniske Universitet, Riso Nationallaboratoriet for Baeredygtig Energi. https://backend.orbit.dtu.dk/ws/portalfiles/portal/6238105/prod11321520607029.Technologies_for_Adaptation-Perspectives_and_Practical_Experiences%5D.pdf.
- Chui, Glennda. 1999. "Jammin' for the Salmon." *San Jose Mercury News*, January 26, 1999. <https://www.wcc.nrcs.usda.gov/ftpref/wntsc/strmRest/EngineeredLogJamsForSalmon.pdf>.
- Clarke, L., L. Nichols, R. Vallario, M. Hejazi, J. Horing, A.C. Janetos, K. Mach, M. Mastrandrea, M. Orr, B.L. Preston, P. Reed, R.D. Sands, and D.D. White, 2018: Sector Interactions, Multiple Stressors, and Complex Systems. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 638–668. https://web.archive.org/web/20190405062855/https://nca2018.globalchange.gov/downloads/NCA4_Ch17_Complex-Systems_Full.pdf.
- Clements, Janet, Robert Raucher, Karen Raucher, Lorine Giangola, Michael Duckworth, Stacey Isaac Berahzer, Jeff Hughes, Scott Rubin, and Roger Colton. 2017. "Customer Assistance Programs for Multi-Family Residential and Other Hard-to-Reach Customers." Project #4557.

- Climate Adaptation Knowledge Exchange. n.d. “Climate Adaptation Monitoring, Evaluation, and Efficacy Testing Dashboard.” Climate Adaptation Knowledge Exchange (CAKE). Accessed April 22, 2025. <https://www.cakex.org/about-monitoring-evaluation-dashboard>.
- Climate Adaptation Science Centers. n.d. “Preparing for Drought on the Wind River Indian Reservation.” Climate Adaptation Science Centers. Accessed April 22, 2025. <https://www.usgs.gov/programs/climate-adaptation-science-centers/preparing-drought-wind-river-indian-reservation>.
- Climate XChange. n.d. “Communicating the Climate Crisis.” *Climate-XChange* (blog). Accessed June 14, 2023. <https://climate-xchange.org/communicating-the-climate-crisis/>.
- Cochise County. n.d. “County Toilet Rebate Program.” Accessed February 19, 2025. <https://www.cochise.az.gov/558/County-Toilet-Rebate-Program>.
- Coen, Deborah R. 2021. “A Brief History of Usable Climate Science.” *Climatic Change* 167 (3): 51. <https://doi.org/10.1007/s10584-021-03181-2>.
- Cohen-Shacham, E., G. Walters, C. Janzen, and S. Maginnis, eds. 2016. *Nature-Based Solutions to Address Global Societal Challenges*. IUCN International Union for Conservation of Nature. <https://doi.org/10.2305/IUCN.CH.2016.13.en>.
- Colorado Water Conservation Board. 2023. “Colorado Water Plan.” Colorado: Colorado Water Conservation Board. https://dnrweblink.state.co.us/CWCB/0/edoc/219188/Colorado_WaterPlan_2023_Digital.pdf.
- _____. n.d.-a. “Basin Roundtables.” Colorado Department of Natural Resources. Accessed February 11, 2025. <https://cwcb.colorado.gov/about-us/basin-roundtables>.
- _____. n.d.-b. “Water Supply Planning.” Colorado Department of Natural Resources. Accessed February 12, 2025. <https://cwcb.colorado.gov/focus-areas/supply/water-supply-planning>.
- Communities Unlimited. n.d. “Community Infrastructure.” *Communities Unlimited* (blog). Accessed April 18, 2025. <https://communitiesu.org/environmental/>.
- Community Planning Assistance for Wildfire. n.d. “About Us.” Community Planning Assistance for Wildfire. Accessed April 18, 2025. <https://cpaw.headwaterseconomics.org/who-we-are/>.
- Conservation International. n.d. “Green-Gray Infrastructure.” Accessed October 22, 2024. <https://www.conservation.org/projects/green-gray-infrastructure>.
- Cooley, Heather, Morgan Shimabuku, and Christine DeMyers. 2022. “Advancing Affordability through Water Efficiency – Pacific Institute.” Oakland, CA: Pacific Institute. <https://pacinst.org/publication/advancing-affordability-through-water-efficiency/>.
- Cooper, Nigel, Emily Brady, Helen Steen, and Rosalind Bryce. 2016. “Aesthetic and Spiritual Values of Ecosystems: Recognising the Ontological and Axiological Plurality of Cultural Ecosystem ‘Services.’” *Ecosystem Services*, Shared, plural and cultural values, 21 (October):218–29. <https://doi.org/10.1016/j.ecoser.2016.07.014>.

- Copeland, Claudia. 2014. "Green Infrastructure and Issues in Managing Urban Stormwater." Congressional Research Service. <https://crsreports.congress.gov/product/pdf/R/R43131>.
- Corum, Lyn. 2017. "Potable Reuse Project Case Studies." WaterWorld. 2017. <https://www.waterworld.com/drinking-water-treatment/article/14070507/potable-reuse-project-case-studies>.
- Council on Environmental Quality. n.d. "Climate and Economic Justice Screening Tool." Climate and Economic Justice Screening Tool. Accessed September 6, 2024. <https://screening-tools.com/climate-economic-justice-screening-tool>.
- Cousins, Joshua J. 2021. "Justice in Nature-Based Solutions: Research and Pathways." *Ecological Economics* 180 (February):106874. <https://doi.org/10.1016/j.ecolecon.2020.106874>.
- _____. 2024. "Just Nature-Based Solutions and the Pursuit of Climate Resilient Urban Development." *Landscape and Urban Planning* 247 (July):105054. <https://doi.org/10.1016/j.landurbplan.2024.105054>.
- Cozzetto, Karen, Colleen Cooley, and April Taylor. 2021. "Drinking Water Infrastructure." In *Status of Tribes and Climate Change Report*, edited by D Marks-Marino, 142–58. Flagstaff, AZ: Institute for Tribal Environmental Professionals, Northern Arizona University. <https://sites.google.com/view/stacc2021-itep/home>.
- Craig, R.K. 2020. "Water Law and Climate Change in the United States: A Review of the Legal Scholarship." *WIREs Water* 7 (3). <https://doi.org/10.1002/wat2.1423>.
- Cromartie, John, and Shawn Bucholtz. 2008. "Defining the 'Rural' in Rural America." *Amber Waves*, US Department of Agriculture, Economic Research Services, 6 (3). <https://www.ers.usda.gov/amber-waves/2008/june/defining-the-rural-in-rural-america>.
- Cruikshank, Julie. 2001. "Glaciers and Climate Change: Perspectives from Oral Tradition." *Arctic* 54 (4): 377–93. <https://www.jstor.org/stable/40512394>.
- Cutter, Susan L., Kevin D. Ash, and Christopher T. Emrich. 2016. "Urban–Rural Differences in Disaster Resilience." *Annals of the American Association of Geographers* 106 (6): 1236–52. <https://doi.org/10.1080/24694452.2016.1194740>.
- Dale, Ann, and Lenore L. Newman. 2009. "Sustainable Development for Some: Green Urban Development and Affordability." *Local Environment* 14 (7): 669–81. <https://doi.org/10.1080/13549830903089283>.
- David-Chavez, Dominique M., and Michael C. Gavin. 2018. "A Global Assessment of Indigenous Community Engagement in Climate Research." *Environmental Research Letters* 13 (12): 123005. <https://doi.org/10.1088/1748-9326/aaf300>.
- Davis Henderson, Katie. 2019. "Flushing Away the Census Toilet Question." LinkedIn. 2019. <https://www.linkedin.com/pulse/flushing-away-census-toilet-question-katie-davis-henderson/>.

- Davis, J.P., and M.P. Teodoro. 2014. "Valuation of Water and Wastewater Utility Assets." In *Water and Wastewater Financing and Pricing*, edited by George A. Raftelis, 4th ed., Chpt. 21. New York, NY: CRC Press. <https://doi.org/10.1201/b17255-29>.
- Deitz, Shiloh, and Katie Meehan. 2019. "Plumbing Poverty: Mapping Hot Spots of Racial and Geographic Inequality in U.S. Household Water Insecurity." *Annals of the American Association of Geographers* 109 (4): 1092–1109. <https://doi.org/10.1080/24694452.2018.1530587>.
- Delaware Health and Social Services. 2023. "DPH Launches New Financial Aid Program for Private Well Owners, Offers Free Water Testing Kits to Delaware Residents." Delaware News, Division of Public Health. August 31, 2023. <https://news.delaware.gov/2023/08/31/dph-launches-new-financial-aid-program-for-private-well-owners-offers-free-water-testing-kits-to-delaware-residents/>.
- Denali Commission. n.d. "Village Infrastructure Protection." Accessed January 24, 2025. <https://denali.gov/programs/village-infrastructure-protection/>.
- DeNies, Ramona. 2019. "Restoring the Quillayute, Before It Floods La Push." *Wild Salmon Center* (blog). December 9, 2019. <https://wildsalmoncenter.org/2019/12/09/restoring-the-quillayute-before-it-floods-la-push/>.
- Department of Legislative Services. 2018. "Preliminary Evaluation of the State Board of Well Drillers." <https://dls.maryland.gov/pubs/prod/SunsetRevEnv/WellDrillers/Prelim-Well-Drillers-2018.pdf>.
- Deutsch, William G., and Sergio S. Ruiz-Córdova. 2015. "Trends, Challenges, and Responses of a 20-Year, Volunteer Water Monitoring Program in Alabama." *Ecology and Society* 20 (3). <https://www.jstor.org/stable/26270232>.
- Dhaka, Krishna P., and Lizette R. Chevalier. 2017. "Managing Urban Stormwater for Urban Sustainability: Barriers and Policy Solutions for Green Infrastructure Application." *Journal of Environmental Management* 203 (December):171–81. <https://doi.org/10.1016/j.jenvman.2017.07.065>.
- Diamond, Emily Pechar, Robert Bonnie, and Elizabeth Rowe. 2020. "Rural Attitudes on Climate Change Lessons from National and Midwest Polling and Focus Groups." Duke Nicholas Institute for Environmental Policy Solutions; The University of Rhode Island. https://nicholasinstitute.duke.edu/sites/default/files/publications/Rural-Attitudes-on-Climate-Change-Midwest_1.pdf.
- Dickson, S. E., C. J. Schuster-Wallace, and J. J. Newton. 2016. "Water Security Assessment Indicators: The Rural Context." *Water Resources Management* 30 (5): 1567–1604. <https://doi.org/10.1007/s11269-016-1254-5>.
- Dictionary.com. 2025a. "Disinformation." Dictionary.Com. March 28, 2025. <https://www.dictionary.com/browse/disinformation>.

- _____. 2025b. "Misinformation." Dictionary.Com. March 28, 2025. <https://www.dictionary.com/browse/misinformation>.
- Diekman, Kristine. n.d. "Run Dry." Run Dry. Accessed April 23, 2025. <http://rundry.org>.
- DigDeep. n.d.-a. "About the Colonias Water Project." Colonias Water Project. Accessed February 7, 2025. <https://www.coloniaswaterproject.org/about>.
- _____. n.d.-b. "About the Project." Navajo Water Project. Accessed August 26, 2024. <https://www.navajowaterproject.org/project-specifics>.
- _____. n.d.-c. "Navajo Water Project." Navajo Water Project. Accessed August 26, 2024. <https://www.navajowaterproject.org>.
- DigDeep and Kohler Company. n.d. "Water Is Life Fund." DIGDEEP. Accessed April 22, 2025. <https://www.digdeep.org/waterislifefund>.
- Diringer, Sarah, Anne Thebo, Heather Cooley, Morgan Shimabuku, Rober Wilkinson, and McKenzie Bradford. 2019. "Moving Toward a Multi-Benefit Approach for Water Management." Oakland, CA: Pacific Institute. <https://pacinst.org/publication/moving-toward-multi-benefit-approach/>.
- Dobbin, Kristin B., Amanda L. Fencl, Gregory Pierce, Melissa Beresford, Silvia Gonzalez, and Wendy Jepson. 2023. "Understanding Perceived Climate Risks to Household Water Supply and Their Implications for Adaptation: Evidence from California." *Climatic Change* 176 (4): 40. <https://doi.org/10.1007/s10584-023-03517-0>.
- Dobbin, Kristin B., Justin McBride, and Gregory Pierce. 2023. "Panacea or Placebo? The Diverse Pathways and Implications of Drinking Water System Consolidation." *Water Resources Research* 59 (12): e2023WR035179. <https://doi.org/10.1029/2023WR035179>.
- Donahue, Bill. 2024. "What Will It Take to Tackle Water Scarcity on the Navajo Nation?" Natural Resources Defense Council. September 26, 2024. <https://www.nrdc.org/stories/what-will-it-take-tackle-water-scarcity-navajo-nation>.
- Douglas, Leah. 2024. "Number of US Farms Falls and Size Increases, Census Shows." US News & World Report. 2024. <https://www.usnews.com/news/top-news/articles/2024-02-13/number-of-us-farms-falls-and-size-increases-census-shows>.
- Doyle, John T., Larry Kindness, James Realbird, Margaret J. Eggers, and Anne K. Camper. 2018. "Challenges and Opportunities for Tribal Waters: Addressing Disparities in Safe Public Drinking Water on the Crow Reservation in Montana, USA." *International Journal of Environmental Research and Public Health* 15 (4): 567. <https://doi.org/10.3390/ijerph15040567>.
- Drakes, Oronde, Eric Tate, Jayton Rainey, and Samuel Brody. 2021. "Social Vulnerability and Short-Term Disaster Assistance in the United States." *International Journal of Disaster Risk Reduction* 53 (February):102010. <https://doi.org/10.1016/j.ijdrr.2020.102010>.

- Drugan, Tim. 2023. “Sudden Water Rate Hikes Reflect Lafayette’s Climate and Water Struggles.” *The Boulder Reporting Lab*, July 26, 2023, sec. Water. <http://boulderreportinglab.org/2023/07/26/sudden-water-rate-hikes-reflect-lafayettes-climate-change-and-water-struggles/>.
- Duke Bass Connections. n.d. “ACRE-Duke Partnership to Improve Sanitation Access in Lowndes County, Alabama (2018–2019).” Accessed April 18, 2025. <https://bassconnections.duke.edu/project/acre-duke-partnership-improve-sanitation-access-lowndes-county-alabama-2018-2019/>.
- Dupuits, Emilie, Alexandra Garcés, Luis Daniel Llambí, and Macarena Bustamante. 2024. “Strategies for Monitoring and Evaluation of Climate Change Adaptation: Localizing Global Approaches into Andean Realities.” *Npj Climate Action* 3 (1): 1–11. <https://doi.org/10.1038/s44168-023-00097-8>.
- EBP and American Society of Civil Engineers. 2021. “Failure to Act: Economic Impacts of Status Quo Investment Across Infrastructure Systems.” American Society of Civil Engineers (ASCE). https://infrastructurereportcard.org/wp-content/uploads/2021/03/FTA_Econ_Impacts_Status_Quo.pdf.
- Eckstein, Gabriel, Amy Hardberger, Abigail Adams, Jack Beasley, Rebekah Bratcher, Justin Clas, Jackson Field, et al. 2022. “Groundwater Laws and Regulations: Survey of Sixteen U.S. States Volume II.” Texas A&M University School of Law Program in Energy, Environmental & Natural Resources Systems. <https://doi.org/10.37419/EENRS.USStateGroundwaterLaws.2022>.
- Ecosystems Knowledge Network. n.d. “InVEST (Integrated Valuation of Ecosystem Services and Trade-Offs).” Ecosystems Knowledge Network. Accessed April 23, 2025. <https://ecosystemsknowledge.net/resources/tool-assessor/invest-integrated-valuation-of-ecosystem-services-and-trade-offs/>.
- Edin, Kathryn J., Luke H. Shaefer, and Timothy J. Nelson. 2023. *The Injustice of Place*. New York and Boston: Mariner Books. <https://www.harperacademic.com/book/9780063239500/the-injustice-of-place>.
- Ehsani, Nima, Charles J. Vörösmarty, Balázs M. Fekete, and Eugene Z. Stakhiv. 2017. “Reservoir Operations under Climate Change: Storage Capacity Options to Mitigate Risk.” *Journal of Hydrology* 555 (December):435–46. <https://doi.org/10.1016/j.jhydrol.2017.09.008>.
- Environmental and Energy Study Institute. 2019. “Fact Sheet | Nature as Resilient Infrastructure – An Overview of Nature-Based Solutions | White Papers | EESI.” 2019. <https://www.eesi.org/papers/view/fact-sheet-nature-as-resilient-infrastructure-an-overview-of-nature-based-solutions>.
- Environmental Finance Center at UNC Chapel Hill, Corona Environmental, and Abt Associates. 2017. “Navigating Legal Pathways to Rate-Funded Customer Assistance Programs: A Guide for Water and Wastewater Utilities.”

- Environmental Law Institute. 2020. “Enabling Citizen Science Programs at Environmental Agencies: Recommendations to the U.S. Environmental Protection Agency.” https://www.epa.gov/sites/default/files/2020-11/documents/enabling_citizen_science_programs_at_environmental_agencies.pdf.
- Ershad Sarabi, Shahryar, Qi Han, A. Georges L. Romme, Bauke de Vries, and Laura Wendling. 2019. “Key Enablers of and Barriers to the Uptake and Implementation of Nature-Based Solutions in Urban Settings: A Review.” *Resources* 8 (3): 121. <https://doi.org/10.3390/resources8030121>.
- European Commission. 2025. “Green Infrastructure.” April 24, 2025. https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure_en.
- Everett, Glyn, Olalekan Adekola, and Jessica Lamond. 2023. “Developing a Blue-Green Infrastructure (BGI) Community Engagement Framework Template.” *URBAN DESIGN International* 28 (3): 172–88. <https://doi.org/10.1057/s41289-021-00167-5>.
- Federal Emergency Management Agency. 2005. “National Flood Insurance Program (NFIP) Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials -.” FEMA 480. https://www.fema.gov/sites/default/files/documents/fema-480_floodplain-management-study-guide_local-officials.pdf.
- _____. 2020. “A Guide to Supporting Engagement and Resiliency in Rural Communities.” https://web.archive.org/web/20250726051557/https://www.fema.gov/sites/default/files/documents/fema_rural-guide_jan-2021.pdf.
- _____. 2021. “Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities.” https://web.archive.org/web/20250220181500/https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf.
- _____. 2023a. “Building Community Resilience With Nature-Based Solutions: Strategies for Success.” https://web.archive.org/web/20250225123849/https://www.fema.gov/sites/default/files/documents/fema_nature-based-solutions-guide-2-strategies-success_2023.pdf.
- _____. 2023b. “Inclusion, Diversity, Equity and Accessibility in Exercises: Considerations and Best Practices Guide.” Federal Emergency Management Agency (FEMA). https://web.archive.org/web/20250108102645/https://www.fema.gov/sites/default/files/documents/fema_inclusion-diversity-equity-accessibility-exercises.pdf.
- _____. 2025. “Hazard Mitigation Assistance Grants.” March 25, 2025. <https://www.fema.gov/grants/mitigation>.
- _____. n.d. “Lesson 3: Enhancing Coordination.” Accessed April 18, 2025. https://emilms.fema.gov/is_0553a/groups/109.html.

- Feinstein, Laura. 2018. "Measuring Progress Toward Universal Access to Water and Sanitation in California." Oakland, CA: Pacific Institute. <https://pacinst.org/publication/measuring-progress/>.
- Feinstein, Laura, Katie Porter, Darcy Bostic, Morgan Shimabuku, Cindy Paulson, Alex Waite, and Rucker Alex. 2020. "Solutions for Underperforming Drinking Water Systems in California." Pacific Institute. https://pacinst.org/publication/underperforming_water_systems_ca/.
- FEMA Technical Mapping Advisory Council. 2023. "2022 Annual Report." Federal Emergency Management Agency (FEMA). https://www.fema.gov/sites/default/files/documents/fema_tmac-annual-report-2022.pdf.
- Fernandez-Bou, Angel Santiago, J. Pablo Ortiz-Partida, Leticia M. Classen-Rodriguez, Chantelise Pells, Kristin B. Dobbin, Vicky Espinoza, José Manuel Rodríguez-Flores, et al. 2021. "3 Challenges, 3 Errors, and 3 Solutions to Integrate Frontline Communities in Climate Change Policy and Research: Lessons From California." *Frontiers in Climate* 3 (September). <https://doi.org/10.3389/fclim.2021.717554>.
- Flanagan, Sara V., Steven E. Spayd, Nicholas A. Procopio, Steven N. Chillrud, James Ross, Stuart Braman, and Yan Zheng. 2016. "Arsenic in Private Well Water Part 2 of 3: Who Benefits the Most from Traditional Testing Promotion?" *Science of The Total Environment* 562 (August):1010–18. <https://doi.org/10.1016/j.scitotenv.2016.03.199>.
- Flavelle, Christopher, Denise Lu, Veronica Penney, Nadja Popovich, and John Schwartz. 2020. "New Data Reveals Hidden Flood Risk Across America." *The New York Times*, June 29, 2020. <https://www.nytimes.com/interactive/2020/06/29/climate/hidden-flood-risk-maps.html#:~:text=That%20new%20calculation%2C%20which%20takes,on%20federal%20government%20flood%20maps>.
- Frank, Thomas. 2022. "How FEMA Helps White and Rich Americans Escape Floods." *POLITICO*, May 27, 2022. <https://www.politico.com/news/2022/05/27/unfair-fema-climate-program-floods-00032080>.
- Friends of the Rouge. n.d. "Investigate." Friends of the Rouge. Accessed April 22, 2025. <https://therouge.org/what-we-do/investigate/>.
- Frosch, Rachel Morello, Manuel Pastor, Jim Sadd, and Seth Shonkoff. 2009. "The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap." https://drive.google.com/file/d/1BcUBC9yLY1w_zCO2ynjDle_BHEv5fdg/view?usp=sharing&usp=embed_facebook.
- Fry, Natalie. 2025. "NSF-Funded Mobile Energy-Water Reuse System to Support Rural Communities." *University of Nevada, Reno* (blog). 2025. <https://www.unr.edu/nevada-today/news/2025/mobile-energy-water-reuse-systems>.
- Fussell, Elizabeth. 2011. "The Deportation Threat Dynamic and Victimization of Latino Migrants: Wage Theft and Robbery." *The Sociological Quarterly* 52 (4): 593–615. <https://doi.org/10.1111/j.1533-8525.2011.01221.x>.

- Gaffney, Austyn, and Jon Cherry. 2025. “Kentucky’s Mountaintop Mines Are Turned Into Neighborhoods.” *The New York Times*, January 28, 2025, sec. Climate. <https://www.nytimes.com/2025/01/28/climate/kentuckys-strip-mines-get-turned-into-neighborhoods.html>.
- Gasteyer, Stephen, and Keith Taylor. 2009. “Assessing the Environmental and Capacity Development Outcomes of Small Water System Board and Management Training.” *Midwest Technical Assistance Center*. https://www.academia.edu/888354/Assessing_the_Environmental_and_Capacity_Development_Outcomes_of_Small_Water_System_Board_and_Management_Training.
- Gibson, Jacqueline MacDonald, Michael Fisher, Allison Clonch, John M. MacDonald, and Philip J. Cook. 2020. “Children Drinking Private Well Water Have Higher Blood Lead than Those with City Water.” *Proceedings of the National Academy of Sciences of the United States of America* 117 (29): 16898–907. <https://doi.org/10.1073/pnas.2002729117>.
- Glade, Sara, and Isha Ray. 2022. “Safe Drinking Water for Small Low-Income Communities: The Long Road from Violation to Remediation.” *Environmental Research Letters* 17 (4): 044008. <https://doi.org/10.1088/1748-9326/ac58aa>.
- Gleick, Peter H. 1996. “Basic Water Requirements for Human Activities: Meeting Basic Needs.” *Water International* 21 (2): 83–92. <https://doi.org/10.1080/02508069608686494>.
- Gleick, Peter H., Amanda Bielawski, and Heather Cooley. 2021. “The U.S. Infrastructure Investment and Jobs Act: Water Components.” Pacific Institute. <https://pacinst.org/the-u-s-infrastructure-plan-water-components/>.
- Gonzalez, Rosa. 2017. “Community-Driven Climate Resilience Planning: A Framework.” National Association of Climate Resilience Planners. <https://www.resilience.org/resources/community-driven-climate-resilience-planning-framework/>.
- Gounaridis, Dimitrios, and Joshua P. Newell. 2024. “The Social Anatomy of Climate Change Denial in the United States.” *Scientific Reports* 14 (1): 2097. <https://doi.org/10.1038/s41598-023-50591-6>.
- Gounaridis, Dimitrios, Wanja Waweru, and Joshua P. Newell. 2024. “Triple Exposure: The Geographic Correlation between Flood Risk, Climate Skepticism, and Social Vulnerability in the United States.” *Environmental Research Letters* 19 (11): 114084. <https://doi.org/10.1088/1748-9326/ad801a>.
- Governor Roy Cooper. 2024. “Hurricane Helene Recovery: Revised Damage and Needs Assessment.” North Carolina Office of State Budget and Management. <https://www.osbm.nc.gov/hurricane-helene-dna/open>.
- Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Communities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel,

- K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437.
https://web.archive.org/web/20190405042634/https://nca2018.globalchange.gov/downloads/NCA4_Ch10_Agriculture_Full.pdf.
- Grabowski, Zbigniew J, Timon McPhearson, A Marissa Matsler, Peter Groffman, and Steward TA Pickett. 2022. “What Is Green Infrastructure? A Study of Definitions in US City Planning.” *Frontiers in Ecology and the Environment* 20 (3): 152–60. <https://doi.org/10.1002/fee.2445>.
- Graff, Frank. 2024. “Rising Sea Levels Threaten Coastal Septic Systems.” PBS North Carolina. 2024. <https://www.pbsnc.org/blogs/science/rising-sea-levels-threaten-coastal-septic-systems/>.
- Graham, Duncan J., Marc F. P. Bierkens, and Michelle T. H. van Vliet. 2024. “Impacts of Droughts and Heatwaves on River Water Quality Worldwide.” *Journal of Hydrology* 629 (February):130590. <https://doi.org/10.1016/j.jhydrol.2023.130590>.
- Granit, Ian. 2020. “The Digital Divide: Effects on Distribution of Wealth and Resources and Climate Change” 1 (January):7–38.
- Great Lakes Integrated Sciences and Assessments. n.d. “Adaptation Monitoring and Evaluation Toolkit.” Accessed February 3, 2025. <https://glisa.umich.edu/resources-tools/adaptation-monitoring-and-evaluation-toolkit/>.
- Greer, Robert A. 2020. “A Review of Public Water Infrastructure Financing in the United States.” *WIREs Water* 7 (5): e1472. <https://doi.org/10.1002/wat2.1472>.
- Grube, Laura E., Rosemarie Fike, and Virgil Henry Storr. 2018. “Navigating Disaster: An Empirical Study of Federal Assistance Following Hurricane Sandy.” *Eastern Economic Journal* 44 (4): 576–93. <https://doi.org/10.1057/s41302-017-0098-x>.
- Gupta, Neha, Susan Craig, Ray Quay, Ryan Handy, and Kristen Keener Busby. 2024. “Navigating Uncertainty: Collaborative Solutions for Sustainable Water Management in the Rural West.” Arizona Water Innovation Initiative. 2024. <https://azwaterinnovation.asu.edu/navigating-uncertainty-collaborative-solutions-sustainable-water-management-rural-west>.
- Guston, David H. 2001. “Boundary Organizations in Environmental Policy and Science: An Introduction.” *Science, Technology, & Human Values* 26 (4): 399–408.
<https://doi.org/10.1177/016224390102600401>.
- Hanrahan, Ryan. 2024. “Ogallala Aquifer Depletion Threatening Rural Communities & Ag.” *Farm Policy News* (blog). January 31, 2024. <https://farmpolicynews.illinois.edu/2024/01/ogallala-aquifer-depletion-threatening-rural-communities-ag/>.

- Hansen, Katy, Sarah Hughes, Andrea Paine, and James Polidori. 2021. “Drinking Water Equity: Analysis and Recommendations for the Allocation of the State Revolving Funds.” Environmental Policy Innovation Center. https://static1.squarespace.com/static/611cc20b78b5f677dad664ab/t/614a45ffeac8517336243cdb/1632257542836/SRFs_Drinking-Water-Analysis.pdf.
- Hasert, Ryan, Chandler Countryman, Amelia Marchand, Kylie Avery, Meade Krosby, and K. M. Poe. 2024. “Climate Adaptation Barriers and Needs Experienced by Northwest Coastal Tribes.” https://cig.uw.edu/wp-content/uploads/sites/2/2024/08/Adaptation-Barriers-NW-Coastal-Tribes_2024.pdf.
- Headwaters Economics. 2021. “Improving Benefit-Cost Analyses for Rural Areas.” Headwaters Economics. <https://headwaterseconomics.org/equity/improving-benefit-cost-analyses/>.
- _____. 2023. “Livingston, MT.” Flood Wise Community Solutions. 2023. <https://floodwise.headwaterseconomics.org/project/livingston-mt/>.
- _____. 2024. “A Rural Capacity Map.” Headwaters Economics. 2024. <https://headwaterseconomics.org/equity/rural-capacity-map/>.
- _____. n.d. “FloodWise Community Assistance Program.” Accessed April 16, 2025. <https://floodwise.headwaterseconomics.org/>.
- Hernandez, Patricia. 2023. “Latinos Face Higher Flood Risks than Other Groups.” Headwaters Economics. November 6, 2023. <https://headwaterseconomics.org/natural-hazards/latinos-face-higher-flood-risks/>.
- Hill, Rosemary, Çiğdem Adem, Wilfred V Alanguí, Zsolt Molnár, Yildiz Aumeeruddy-Thomas, Peter Bridgewater, Maria Tengö, et al. 2020. “Working with Indigenous, Local and Scientific Knowledge in Assessments of Nature and Nature’s Linkages with People.” *Current Opinion in Environmental Sustainability*, Indigenous Conceptualizations of ‘Sustainability,’ 43 (April):8–20. <https://doi.org/10.1016/j.cosust.2019.12.006>.
- Holmes, Lillian, Morgan Shimabuku, Laura Feinstein, Peter H. Gleick, Sarah Diringer, and Gregory Pierce. 2020. “Water and the COVID-19 Pandemic: Equity Dimensions of Utility Disconnections in the U.S.” Issue Brief. Oakland, CA: Pacific Institute. <https://pacinst.org/publication/equity-dimensions-of-disconnections/>.
- Howard, Guy, Katrina Charles, Kathy Pond, Anca Brookshaw, Rifat Hossain, and Jamie Bartram. 2010. “Securing 2020 Vision for 2030: Climate Change and Ensuring Resilience in Water and Sanitation Services.” *Journal of Water and Climate Change* 1 (1): 2–16. <https://doi.org/10.2166/wcc.2010.105b>.
- Howard, Guy, Anisha Nijhawan, Adrian Flint, Manish Baidya, Maria Pregmolato, Anish Ghimire, Moti Poudel, et al. 2021. “The How Tough Is WASH Framework for Assessing the Climate Resilience of Water and Sanitation.” *Npj Clean Water* 4 (1): 39. <https://doi.org/10.1038/s41545-021-00130-5>.

- Howell, Junia, and James R Elliott. 2019. “Damages Done: The Longitudinal Impacts of Natural Hazards on Wealth Inequality in the United States.” *Social Problems* 66 (3): 448–67. <https://doi.org/10.1093/socpro/spy016>.
- Huntington, Henry P. 2000. “Using Traditional Ecological Knowledge in Science: Methods and Applications.” *Ecological Applications* 10 (5): 1270–74. [https://doi.org/10.1890/1051-0761\(2000\)010\[1270:UTEKIS\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2).
- ICLEI USA. 2024. “Resilient, Together: FloodWise Communities Learn & Do Cohorts.” March 7, 2024. <https://icleiusa.org/project/resilient-together-floodwise-communities-learn-do-cohorts/>.
- IJszenga, Judith. 2021. “Overcoming Barriers to Urban Nature-Based Solutions Uptake: A Multiple Case Study of New Residential Building Projects in the Netherlands.” Utrecht University. [https://studenttheses.uu.nl/bitstream/handle/20.500.12932/345/IJszenga%20\(2021\).%20Overcoming%20barriers%20to%20urban%20Nature-Based%20Solutions%20uptake%20\(Master%20Thesis\).pdf](https://studenttheses.uu.nl/bitstream/handle/20.500.12932/345/IJszenga%20(2021).%20Overcoming%20barriers%20to%20urban%20Nature-Based%20Solutions%20uptake%20(Master%20Thesis).pdf).
- Indian Health Service. 2024. “Division of Sanitation Facilities Construction (DSEC) Project Dashboard.” ArcGIS Hub. <https://dsfc-ihs-gis.hub.arcgis.com/>.
- Indiana University. n.d. “Fredericktown, Missouri Prepares for Climate Change Drought Risk.” Environmental Resilience Institute. Accessed February 11, 2025. <https://eri.iu.edu/erit/case-studies/fredericktown-missouri-prepares-climate-change-drought-risk.html>.
- INNRCs, dir. 2019. *Indiana NRCS - Restoring Indiana’s Wetlands: Pokagon Band*. <https://www.youtube.com/watch?v=A4cxGBjFb2I>.
- Integrated Water Services, Inc. 2024. “Membrane Bioreactor Solutions.” <https://integratedwaterservices.com/wp-content/uploads/2024/10/MMBR-MBR-BROCHURE-Final-April-2024.pdf>.
- International Institute for Sustainable Development. n.d. “The Sustainable Asset Valuation (SAVi).” Sustainable Asset Valuation (SAVi). Accessed February 14, 2025. <https://www.iisd.org/savi/>.
- International Union for Conservation of Nature. 2020. “IUCN Global Standard for Nature-Based Solutions.”
- _____. 2024. “Human Rights-Based Approach in IUCN’s Global Standard for Nature-Based Solutions.” April 4, 2024. <https://iucn.org/blog/202404/human-rights-based-approach-iucns-global-standard-nature-based-solutions>.
- _____. n.d. “IUCN Online Self-Assessment Tool | Nature-Based Solutions.” Accessed April 23, 2025. <https://nbs-sat.iucn.org/>.

- International Water Association. n.d. “Nature for Water and Sanitation.” International Water Association. Accessed March 31, 2023. <https://iwa-network.org/projects/nature-for-water-and-sanitation/>.
- International Water Centre. n.d. “Water Leadership.” *International Water Centre* (blog). Accessed August 4, 2024. <https://watercentre.org/thematic-areas/water-leadership/>.
- International Water, Sanitation and Hygiene Foundation. 2022. “Finally, a Fix for the Wastewater Crisis in the Alabama Black Belt.” *International Association of Plumbing & Mechanical Officials* (blog). May 9, 2022. <https://52.42.8.140/fix-for-wastewater-crisis-in-alabama-black-belt/>.
- Ivey, Janet L, John Smithers, Rob C de Loë, and Reid D Kreutzwiser. 2004. “Community Capacity for Adaptation to Climate-Induced Water Shortages: Linking Institutional Complexity and Local Actors.” *Environmental Management* 33 (1): 36–47. <https://doi.org/10.1007/s00267-003-0014-5>.
- Jankowski, Caroline, Kristofer Isaacson, Madeline Larsen, Christian Ley, Myles Cook, and Andrew J. Whelton. 2023. “Wildfire Damage and Contamination to Private Drinking Water Wells.” *AWWA Water Science* 5 (1). <https://doi.org/10.1002/aws2.1319>.
- Jantarasami, L.C., R. Novak, R. Delgado, E. Marino, S. McNeeley, C. Narducci, J. Raymond-Yakoubian, L. Singletary, and K. Powys Whyte, 2018: Tribes and Indigenous Peoples. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 572–603. doi: 10.7930/NCA4.2018.CH15. <https://web.archive.org/web/20250630053449/https://nca2018.globalchange.gov/chapter/15/>.
- Jasechko, Scott, and Debra Perrone. 2020. “California’s Central Valley Groundwater Wells Run Dry During Recent Drought.” *Earth’s Future* 8 (4): e2019EF001339. <https://doi.org/10.1029/2019EF001339>.
- Jay, A.K., A.R. Crimmins, C.W. Avery, T.A. Dahl, R.S. Dodder, B.D. Hamlington, A. Lustig, K. Marvel, P.A. Méndez-Lazaro, M.S. Osler, A. Terando, E.S. Weeks, and A. Zycherman, 2023: Ch. 1. Overview: Understanding risks, impacts, and responses. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. <https://web.archive.org/web/20250629214219/https://nca2023.globalchange.gov/#overview>.
- Jijelava, David, and Frank Vanclay. 2018. “How a Large Project Was Halted by the Lack of a Social Licence to Operate: Testing the Applicability of the Thomson and Boutilier Model.” *Environmental Impact Assessment Review* 73 (November):31–40. <https://doi.org/10.1016/j.eiar.2018.07.001>.

- John, Andrew, Rory Nathan, Avril Horne, Michael Stewardson, and J. Angus Webb. 2020. “How to Incorporate Climate Change into Modelling Environmental Water Outcomes: A Review.” *Journal of Water and Climate Change* 11 (2): 327–40. <https://doi.org/10.2166/wcc.2020.263>.
- Johnson, Kenneth, and Daniel Lichter. 2022. “Growing Racial Diversity in Rural America: Results from the 2020 Census.” Carsey School of Public Policy. May 17, 2022. <https://carsey.unh.edu/publication/growing-racial-diversity-rural-america-results-2020-census>.
- Kane, Joseph W., and Anna Singer. 2024. “Exploring and Improving How State Water Funding Flows amid a Surge in Federal Infrastructure Investment.” Brookings Institute. <https://www.brookings.edu/articles/exploring-and-improving-how-state-water-funding-flows-amid-a-surge-in-federal-infrastructure-investment/>.
- Kearns, Faith. 2025. “An Arizona Community Comes Together to Bolster Rural Groundwater Resilience.” Arizona Water Innovation Initiative. 2025. <https://azwaterinnovation.asu.edu/arizona-community-comes-together-bolster-rural-groundwater-resilience>.
- Kentucky Infrastructure Authority. 2024. “KIA Board Report: Kentucky WWaters Program.” Kentucky Infrastructure Authority. <https://kia.ky.gov/kentuckywwaters/Documents/0%20Board%20Report%20KY%20WWATER%20November%202024.pdf>.
- _____. n.d. “Kentucky WWaters - Kentucky Infrastructure Authority.” Kentucky WWaters. Accessed February 10, 2025. <https://kia.ky.gov/kentuckywwaters/Pages/default.aspx>.
- Kentucky Water/Wastewater Agency Response Network (KYWARN). n.d. “KY WARN.” Accessed March 20, 2025. <https://www.kywarn.org/>.
- Kenward, Alyson, Daniel Yawitz, and Urooj Raja. 2013. “Sewage Overflows From Hurricane Sandy.” Princeton, NJ: Climate Central, Princeton. <https://superstormresearchlab.org/wp-content/uploads/2013/07/climate-central-sewage-overflows-from-hurricane-sandy.pdf>.
- Kettle, Nathan P., Sarah F. Trainor, Renee Edwards, Donald Antrobus, Curt Baranowski, Tina Buxbaum, Kevin Berry, et al. 2023. “Building Resilience to Extreme Weather and Climate Events in the Rural Water and Wastewater Sectors.” *JAWRA Journal of the American Water Resources Association* 59 (6): 1511–28. <https://doi.org/10.1111/1752-1688.13151>.
- Kimmerer, Robin Wall. 2013. *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants*. http://archive.org/details/braiding-sweetgrass-indigenous-wisdom-scientific-knowledge-and-the-teachings-of-plants_202212.
- Kirchhoff, Christine J. 2013. “Understanding and Enhancing Climate Information Use in Water Management.” *Climatic Change* 119 (2): 495–509. <https://doi.org/10.1007/s10584-013-0703-x>.

- Klamath River Renewal Corporation. n.d. “Benefits of Klamath River Renewal.” Klamath Renewal. Accessed February 14, 2025. <https://klamathrenewal.org/benefits/>.
- Klastic, Meghan, Amanda Fencl, Julia A. Ekstrom, and Amanda Ford. 2022. “Adapting to Extreme Events: Small Drinking Water System Manager Perspectives on the 2012–2016 California Drought.” *Climatic Change* 170 (3): 26. <https://doi.org/10.1007/s10584-021-03305-8>.
- Klenk, Nicole, Anna Fiume, Katie Meehan, and Cerian Gibbes. 2017. “Local Knowledge in Climate Adaptation Research: Moving Knowledge Frameworks from Extraction to Co-production.” *WIREs Climate Change* 8 (5). <https://doi.org/10.1002/wcc.475>.
- Kolokytha, Elpida, Carlos de Oliveira Galvão, and Ramesh S. V. Teegavarapu. 2017. “Climate Change Impacts and Water Resource Management and Planning.” In *Sustainable Water Resources Planning and Management Under Climate Change*, edited by Elpida Kolokytha, Satoru Oishi, and Ramesh S.V. Teegavarapu, 283–95. Singapore: Springer. https://doi.org/10.1007/978-981-10-2051-3_11.
- Kuhl, Laura, and Alaina Boyle. 2021. “Nature-Based Solutions Valuation Report: Incorporating Climate-Informed Cost-Benefit Analysis into Assessment of Nature-Based Solutions in Latin American and the Caribbean.” School of Public Policy and Urban Affairs, Northeastern University, and United Nations Development Programme. <https://cssh.northeastern.edu/policyschool/wp-content/uploads/sites/2/2021/07/Northeastern-NbS-report-final.pdf>.
- Kuiper, Jacobien F., and Elisabeth Hamin Infield. 2019. “Greenways for Climate Adaptation: Avoiding the ‘Green Paradox’ while Improving Urban Resiliency.” *Fábos Conference on Landscape and Greenway Planning* 6 (1). <https://doi.org/10.7275/strt-d854>.
- Lall, U., T. Johnson, P. Colohan, A. Aghakouchak, C. Brown, G. McCabe, R. Pulwarty, and A. Sankarasubramanian. 2018: Water. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 145–173. <https://web.archive.org/web/20250629220511/https://nca2018.globalchange.gov/chapter/3/>.
- Landes, Laura, Eric LaRose, Sarah Buck, Nathan Ohle, Ted Stiger, Glenn Barnes, Malini Sekhar, and Coye Gerald. 2021. “Regionalization: RCAP’s Recommendations for Water and Wastewater Policy.” Research Report. Rural Community Assistance Partnership (RCAP). <https://www.rcap.org/wp-content/uploads/2021/09/RCAP-Regionalization-Research-Report-May-2021-Final-1.pdf>.
- Landes, Laura, Ashley Zuelke, Sarah Buck, and Nathan Ohle. 2020. “Resiliency through Water and Wastewater System Partnerships: 10 Lessons from Community Leaders.” Research Report. Rural Community Assistance Partnership (RCAP). https://rcap.org/wp-content/uploads/2021/09/RCAP-Regionalization-Research-Report_March-2020_Pages-1.pdf.

- Langridge, Suzanne M., Eric H. Hartge, Ross Clark, Katie Arkema, Gregory M. Verutes, Erin E. Prahler, Sarah Stoner-Duncan, et al. 2014. "Key Lessons for Incorporating Natural Infrastructure into Regional Climate Adaptation Planning." *Ocean & Coastal Management* 95 (July):189–97. <https://doi.org/10.1016/j.ocecoaman.2014.03.019>.
- LEO Network. n.d. "Local Environmental Observer (LEO) Network." [Www.Leonetwork.Org](http://www.leonetwork.org). Accessed April 22, 2025. <https://www.leonetwork.org>.
- Leung, Valerie A., Nathan Woiwode, and Mark P. Smith. 2018. "A Procurement Guide to Nature-Based Solutions." The Nature Conservancy. https://nrcsolutions.org/wp-content/uploads/2018/02/NBS_Procurement_Guide.pdf.
- Litvack, Emily. 2019. "On Navajo Nation, Taking Clean Water Off the Grid." September 26, 2019. <https://research.arizona.edu/stories/navajo-nation-taking-clean-water-grid>.
- Livelihoods Knowledge Exchange Network. 2024a. "Community Engagement Guide." 2024. <https://sites.google.com/likenknowledge.org/community-engagement-guide/home>.
- _____. 2024b. "Community Engagement Guide - Participatory Action Research Methods." 2024. <https://sites.google.com/likenknowledge.org/community-engagement-guide/planning-for-a-community-meeting/participatory-action-research-methods>.
- _____. 2024c. "Harlan County Water Resilience Toolkit." 2024. <https://sites.google.com/likenknowledge.org/harlan-county-water-toolkit/home>.
- _____. n.d.-a. "The LiKEN Framework: Participatory Action Research (PAR)." Accessed October 29, 2024. <https://sites.google.com/view/the-liken-framework/participatory-action-research-par>.
- _____. n.d.-b. "Water Collaboratory." LiKEN Knowledge. Accessed April 22, 2025. <https://www.likenknowledge.org/programs/water-collaboratory>.
- Lockhart, K. M., A. M. King, and T. Harter. 2013. "Identifying Sources of Groundwater Nitrate Contamination in a Large Alluvial Groundwater Basin with Highly Diversified Intensive Agricultural Production." *Journal of Contaminant Hydrology* 151 (August):140–54. <https://doi.org/10.1016/j.jconhyd.2013.05.008>.
- London, Jonathan K, Amanda Fencl, Sara Watterson, Yasmina Choueiri, Phoebe Seaton, Jennifer Jarin, Mia Dawson, et al. 2021. "Disadvantaged Unincorporated Communities and the Struggle for Water Justice in California." *Water Alternatives* 14 (2): 520–45. https://scholarship.law.columbia.edu/faculty_scholarship/3598/.
- Lowrey, JL, Aj Ray, and Rs Webb. 2009. "Factors Influencing the Use of Climate Information by Colorado Municipal Water Managers." *Climate Research* 40 (October):103–19. <https://doi.org/10.3354/cr00827>.

- Lyle, Zia J., Jeanne M. VanBriesen, and Constantine Samaras. 2023. "Drinking Water Utility-Level Understanding of Climate Change Effects to System Reliability." *ACS ES&T Water* 3 (8): 2395–2406. <https://doi.org/10.1021/acsestwater.3c00091>.
- MacDonald, James M., and Robert A. Hoppe. 2018. "Examining Consolidation in U.S. Agriculture." Economic Research Service, US Department of Agriculture. 2018. <https://www.ers.usda.gov/amber-waves/2018/march/examining-consolidation-in-u-s-agriculture/>.
- Mach, K.J., R. Vallario, J.R. Arnold, C. Brelsford, K.V. Calvin, A.N. Flores, J. Gao, K. Jagannathan, D. Judi, C.E. Martín, F.C. Moore, R. Moss, E. Nance, B. Rashleigh, P.M. Reed, L. Shi, and L.L. Turek-Hankins, 2023: Ch. 18. Sector interactions, multiple stressors, and complex systems. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. <https://web.archive.org/web/20250630050654/https://nca2023.globalchange.gov/chapter/18/>.
- Makarigakis, Alexandros K., and Blanca Elena Jimenez-Cisneros. 2019. "UNESCO's Contribution to Face Global Water Challenges." *Water* 11 (2): 388. <https://doi.org/10.3390/w11020388>.
- Maldonado, Alejandra, Timothy W. Collins, and Sara E. Grineski. 2016. "Hispanic Immigrants' Vulnerabilities to Flood and Hurricane Hazards in Two United States Metropolitan Areas." *Geographical Review* 106 (1): 109–35. <https://doi.org/10.1111/j.1931-0846.2015.12103.x>.
- Maldonado, Julie, T. M. Bull Bennett, Karletta Chief, Patricia Cochran, Karen Cozzetto, Bob Gough, Margaret Hiza Redsteer, Kathy Lynn, Nancy Maynard, and Garrit Voggeser. 2016. "Engagement with Indigenous Peoples and Honoring Traditional Knowledge Systems." *Climatic Change* 135 (1): 111–26. <https://doi.org/10.1007/s10584-015-1535-7>.
- Malecki, Kristen M. C., Amy A. Schultz, Dolores J. Severtson, Henry A. Anderson, and James A. VanDerslice. 2017. "Private-Well Stewardship among a General Population Based Sample of Private Well-Owners." *Science of The Total Environment* 601–602 (December):1533–43. <https://doi.org/10.1016/j.scitotenv.2017.05.284>.
- Marshall, Joey, Chase Sawyer, Heather King, Bethany DeSalvo, and Walter Peacock. 2024. "More Than Half a Million North Carolinians Under Disaster Declaration After Hurricane Helene Were at High Social Vulnerability to Disasters." United States Census Bureau. 2024. <https://www.census.gov/library/stories/2024/10/hurricane-helene.html>.
- Martin, D. M., and M. Mazzotta. 2018. "Non-Monetary Valuation Using Multi-Criteria Decision Analysis: Sensitivity of Additive Aggregation Methods to Scaling and Compensation Assumptions." *Ecosystem Services* 29 (February):13–22. <https://doi.org/10.1016/j.ecoser.2017.10.022>.
- Marvel, K., W. Su, R. Delgado, S. Aarons, A. Chatterjee, M.E. Garcia, Z. Hausfather, K. Hayhoe, D.A. Hence, E.B. Jewett, A. Robel, D. Singh, A. Tripathi, and R.S. Vose, 2023: Ch. 2. Climate

trends. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

<https://web.archive.org/web/20250630041240/https://nca2023.globalchange.gov/chapter/2/>.

Marwaha, Nisha, George Kourakos, Elad Levintal, and Helen E. Dahlke. 2021. “Identifying Agricultural Managed Aquifer Recharge Locations to Benefit Drinking Water Supply in Rural Communities.” *Water Resources Research* 57 (3): e2020WR028811.

<https://doi.org/10.1029/2020WR028811>.

Massachusetts Department of Environmental Protection. n.d. “Private Wells.” Accessed December 16, 2024. <https://www.mass.gov/private-wells>.

Massachusetts Executive Office of Energy and Environmental Affairs. n.d. “Climate Grant Viewer.” Map Tool. Accessed May 21, 2025.

https://experience.arcgis.com/experience/fd26505b82bc49b1bac525dc95a2a50a/page/MVP-Grant-Programs?views=Action-Grants-View#data_s=id%3AdataSource_1-195c8b833ae-layer-11%3A205.

Mathias, John, Desirée D. Burns, Ellen Piekalkiewicz, Juyeong Choi, and Giselle Feliciano. 2022. “Roles of Nonprofits in Disaster Response and Recovery: Adaptations to Shifting Disaster Patterns in the Context of Climate Change.” *Natural Hazards Review* 23 (3): 04022011.

[https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000559](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000559).

Matthews, Tony, Alex Y. Lo, and Jason A. Byrne. 2015. “Reconceptualizing Green Infrastructure for Climate Change Adaptation: Barriers to Adoption and Drivers for Uptake by Spatial Planners.” *Landscape and Urban Planning* 138 (June):155–63.

<https://doi.org/10.1016/j.landurbplan.2015.02.010>.

McNeeley, Shannon M. 2009. “Seasons Out of Balance: Climate Change Impacts, Vulnerability, and Sustainable Adaptation in Interior Alaska, Ph.D. Dissertation.” *Department of Anthropology*. Dissertation, Fairbanks: University of Alaska Fairbanks.

https://www.academia.edu/7378703/Mc_Neeley_2009_Seasons_Out_of_Balance_Climate_Change_Impacts_Vulnerability_and_Sustainable_Adaptation_in_Interior_Alaska_PhD_Dissertation.

_____. 2012. “Examining Barriers and Opportunities for Sustainable Adaptation to Climate Change in Interior Alaska.” *Climatic Change* 111 (3–4): 835–57.

<https://doi.org/10.1007/s10584-011-0158-x>.

_____. 2014. “A ‘Toad’s Eye’ View of Drought: Regional Socio-Natural Vulnerability and Responses in 2002 in Northwest Colorado.” *Regional Environmental Change* 14 (August):1451–61. <https://doi.org/10.1007/s10113-014-0585-0>.

_____. 2017. “Sustainable Climate Change Adaptation in Indian Country.” *Weather, Climate, and Society* 9 (3): 393–404. <https://doi.org/10.1175/WCAS-D-16-0121.1>.

- _____. 2020. “Wind River Reservation Drought Preparedness.” Climate Adaptation Knowledge Exchange. 2020. <https://www.cakex.org/case-studies/wind-river-reservation-drought-preparedness>.
- McNeeley, Shannon M., Tyler Beeton, Crystal Stiles, N. Umphlett, and M. Cottenoir. 2020. “Wind River Reservation Drought Management Plan.” Fort Collins, CO and Lander, WY: Colorado State University and Wind River Reservation Office of the Tribal Water Engineer.
- McNeeley, Shannon M., Candida F. Dewes, Crystal J. Stiles, Tyler A. Beeton, Imtiaz Rangwala, Michael T. Hobbins, and Cody L. Knutson. 2018. “Anatomy of an Interrupted Irrigation Season: Micro-Drought at the Wind River Indian Reservation.” *Climate Risk Management* 19:61–82. <https://doi.org/10.1016/j.crm.2017.09.004>.
- McNeeley, Shannon M., and Heather Lazrus. 2014. “The Cultural Theory of Risk for Climate Change Adaptation.” *Weather, Climate, and Society* 6 (4): 506–19. <https://doi.org/10.1175/WCAS-D-13-00027.1>.
- McNeeley, Shannon M., Morgan Shimabuku, Rebecca Anderson, Rachel Will, and Jessica Dery. 2025. “Achieving Equitable, Climate-Resilient Water and Sanitation for Frontline Communities.” Water, Sanitation, and Climate Change in the United States Series, Part 3. Oakland, CA: Pacific Institute. <https://pacinst.org/publication/achieving-equitable-water-and-sanitation/>.
- McNeeley, Shannon M., and Martha D. Shulski. 2011. “Anatomy of a Closing Window: Vulnerability to Changing Seasonality in Interior Alaska.” *Global Environmental Change* 21 (2): 464–73. <https://doi.org/10.1016/j.gloenvcha.2011.02.003>.
- Meadow, Alison M., Daniel B. Ferguson, Zack Guido, Alexandra Horangic, Gigi Owen, and Tamara Wall. 2015. “Moving toward the Deliberate Coproduction of Climate Science Knowledge.” *Weather, Climate, and Society* 7 (2): 179–91. <https://doi.org/10.1175/WCAS-D-14-00050.1>.
- Medalie, L., A.E. Galanter, A.J. Martinez, A.A. Archer, C.L. Luukkonen, M.A. Harris, and J.V. Haynes. 2025. “Water Use across the Conterminous United States, Water Years 2010–20.” Chap. D of U.S. Geological Survey Integrated Water Availability Assessment—2010–20: U.S. Geological Survey Professional Paper 1894–D. <https://doi.org/10.3133/pp1894D>.
- Meehan, Katie, Jason R. Jurjevich, Nicholas M. J. W. Chun, and Justin Sherrill. 2020. “Geographies of Insecure Water Access and the Housing–Water Nexus in US Cities.” *Proceedings of the National Academy of Sciences* 117 (46): 28700–707. <https://doi.org/10.1073/pnas.2007361117>.
- Meixner, Thomas, Andrew H. Manning, David A. Stonestrom, Diana M. Allen, Hoori Ajami, Kyle W. Blasch, Andrea E. Brookfield, et al. 2016. “Implications of Projected Climate Change for Groundwater Recharge in the Western United States.” *Journal of Hydrology* 534 (March):124–38. <https://doi.org/10.1016/j.jhydrol.2015.12.027>.

- Melendez, Amanda, and Mariantonieta Gutierrez Soto. 2024. "Flood Resilience Quantification Framework of Rural Communities: Case Study of Harlan County, Kentucky." *Natural Hazards Review* 25 (4): 05024009. <https://doi.org/10.1061/NHREFO.NHENG-1949>.
- Michigan State University. 2019. "Marquette Area Climate and Health Adaptation Guide - Volume III." https://www.canr.msu.edu/climate-change/uploads/files/9_12_2019_FINAL_Volume%20III.pdf.
- Michigan State University and Michigan Department of Health and Human Services. 2020. "Climate and Health Adaptation Planning Guide for Michigan Communities." <https://www.canr.msu.edu/resources/climate-and-health-adaptation-planning-guide-for-michigan-communities>.
- Mile High Youth Corps. n.d. "Free Energy & Water Services." Accessed January 17, 2025. <https://www.milehighyouthcorps.org/free-install-services/>.
- Miller, Meghan, Ryan Cronk, Tori Klug, Emma R. Kelly, Nikki Behnke, and Jamie Bartram. 2019. "External Support Programs to Improve Rural Drinking Water Service Sustainability: A Systematic Review." *Science of The Total Environment* 670 (June):717–31. <https://doi.org/10.1016/j.scitotenv.2019.03.069>.
- Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer. 2008. "Stationarity Is Dead: Whither Water Management?" *Science* 319 (5863): 573–74. <https://doi.org/10.1126/science.1151915>.
- Mississippi State University Extension Service. n.d. "Public Water System Assistance Program." <http://extension.msstate.edu/water#:~:text=Board%20members%20are%20trained%20in,kingery@msstate.edu>.
- Missouri Stream Team. n.d. "Home." Accessed April 22, 2025. <https://mostreamteam.org/>.
- Mitchell, James K., Karen O'Neill, Melanie McDermott, and Mariana Leckner. 2016. "Towards a Transformative Role for Local Knowledge in Post-Disaster Recovery: Prospects for Co-Production in the Wake of Hurricane Sandy." *Journal of Extreme Events* 03 (01): 1650003. <https://doi.org/10.1142/S2345737616500032>.
- Mojave Water Agency. 2014. "Final Mojave Region Integrated Regional Water Management Plan." https://www.mojavewater.org/wp-content/uploads/2023/12/mojave_irwm-plan_final_626142.pdf.
- _____. n.d. "Small Water System Assistance Program." Accessed February 12, 2025. <https://www.mojavewater.org/basin-management/small-water-systems-assistance-program/about-the-program/>.
- Mok, Sophie, Ernesta Mačiulytė, Pieter Hein Bult, and Tom Hawxwell. 2021. "Valuing the Invaluable(?)—A Framework to Facilitate Stakeholder Engagement in the Planning of Nature-Based Solutions." *Sustainability* 13 (5): 2657. <https://doi.org/10.3390/su13052657>.

- Montgomery County Department of Environmental Protection. 2025. “RainScapes.” 2025. <https://www.montgomerycountymd.gov/DEP/property-care/rainscapes/index.html>.
- Montgomery Parks. 2025. “Greenscapes Symposium – Virtual Registration Packet.” *Montgomery Parks* (blog). 2025. <https://montgomeryparks.org/parks-and-trails/greenscapes-participant-page/>.
- Morrison, Jim. 2022. “Backed-up Pipes, Stinky Yards: Climate Change Is Wrecking Septic Tanks.” *Washington Post*, April 12, 2022. <https://www.washingtonpost.com/climate-environment/2022/04/12/backed-up-pipes-stinky-yards-climate-change-is-wrecking-septic-tanks/>.
- Morrisette, Micaela. n.d. “WVU to Help Fill Need for Water Workforce in Appalachian Communities.” *Statler College Media Hub*. Accessed March 17, 2025. <https://media.statler.wvu.edu/news/2024/04/10/wvu-to-help-fill-need-for-water-workforce-in-appalachian-communities>.
- Morse, Rick. 2009. “Boundary Organizations and Collaboration.” Community and Economic Development in North Carolina and Beyond. UNC School of Government. 2009. <https://ced.sog.unc.edu/2009/11/boundary-organizations-and-collaboration/>.
- Moser, Susanne C., and L. Dilling. 2004. “Making Climate Hot – Communicating the Urgency and Challenge of Global Climate Change.” *Environment* 46 (10): 32–46.
- Moser, Susanne C., and Lisa Dilling, eds. 2007. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*. Cambridge ; New York: Cambridge University Press.
- Mueller, J. Tom, and Stephen Gasteyer. 2021. “The Widespread and Unjust Drinking Water and Clean Water Crisis in the United States.” *Nature Communications* 12 (1): 3544. <https://doi.org/10.1038/s41467-021-23898-z>.
- Mulhern, Riley, Javad Roostaei, Sara Schwetschenau, Tejas Pruthi, Chris Campbell, and Jacqueline MacDonald Gibson. 2022. “A New Approach to a Legacy Concern: Evaluating Machine-Learned Bayesian Networks to Predict Childhood Lead Exposure Risk from Community Water Systems.” *Environmental Research* 204 (March). <https://doi.org/10.1016/j.envres.2021.112146>.
- Mullin, Megan. 2020. “The Effects of Drinking Water Service Fragmentation on Drought-Related Water Security.” *Science* 368 (6488): 274–77. <https://doi.org/10.1126/science.aba7353>.
- National Conference of State Legislatures. 2022. “State Policy Options for Small and Rural Water Systems.” National Conference of State Legislatures. <https://documents.ncsl.org/wwwncsl/Environment/NCSL-Brief-Small-Water-Systems.pdf>.
- National Drought Mitigation Center. n.d. “U.S. Drought Monitor.” Accessed April 22, 2025. <https://droughtmonitor.unl.edu/>.

- National Fish and Wildlife Foundation. 2021. “Emergency Coastal Resilience Fund.” Nfwf.Org. November 17, 2021. <https://www.nfwf.org/programs/emergency-coastal-resilience-fund>.
- _____. 2025. “Klamath Basin Forests and Watersheds Restoration 2025.” 2025. <https://www.nfwf.org/programs/klamath-basin-restoration-program/klamath-basin-forests-and-watersheds-restoration-2025>.
- National Oceanic and Atmospheric Administration. 2024. “Climate Adaptation Partnerships Program.” Climate Program Office. 2024. <https://cpo.noaa.gov/divisions-programs/climate-and-societal-interactions/cap-risa/>.
- _____. n.d. “Nature-Based Solutions.” Office for Coastal Management, Digital Coast. Accessed October 29, 2024. <https://coast.noaa.gov/digitalcoast/topics/green-infrastructure.html>.
- National Oceanic and Atmospheric Administration, Climate Program Office. 2022. “Resilient Rural America Project Offers Two Training Modules.” February 12, 2022. <https://cpo.noaa.gov/resilient-rural-america-project-offers-two-training-modules/>.
- National Rural Water Association. 2020a. “Circuit Rider Program.” *National Rural Water Association* (blog). 2020. <https://nrwa.org/circuit-rider-program/>.
- _____. 2020b. “Sourcewater Protection Program.” National Rural Water Association. April 24, 2020. <https://nrwa.org/sourcewater-protection-program/>.
- _____. n.d.-a. “About.” National Rural Water Association. Accessed March 18, 2025. <https://nrwa.org/about/>.
- _____. n.d.-b. “National Rural Water Apprenticeship Program.” Accessed March 17, 2025. <https://apprenticeship.nrwa.org/pub/index.htm>.
- National Wildlife Federation. 2022. “Nature-Based Solutions Funding Database.” <https://fundingnaturebasedsolutions.nwf.org/>.
- Natural Resources Conservation Service. 2025a. “Emergency Watershed Protection.” April 9, 2025. <https://www.nrcs.usda.gov/programs-initiatives/ewp-emergency-watershed-protection>.
- _____. 2025b. “Wetland Reserve Easements.” USDA Natural Resources Conservation Service. February 4, 2025. <https://www.nrcs.usda.gov/programs-initiatives/wre-wetland-reserve-easements>.
- _____. n.d. “Water Supply Forecasting.” US Department of Agriculture. Accessed April 22, 2025. <https://www.nrcs.usda.gov/programs-initiatives/sswsf-snow-survey-and-water-supply-forecasting-program/water-supply>.
- Navajo Nation Department of Water Resources. 2003. “Navajo Nation Drought Contingency Plan.” http://www.frontiernet.net/~nndwr_wmb/PDF/Reports/DWRReports/DWR2003%20Navajo%20Nation%20Drought%20Contingency%20Plan.pdf.

- New Mexico Finance Authority. 2022. “Colonias Infrastructure Fund.” 2022. <https://www.nmfinance.com/colonias/>.
- Newtok Village Council. 2017. “Newtok to Mertarvik Relocation.” <https://www.congress.gov/116/meeting/house/108887/witnesses/HHRG-116-II24-Wstate-JordanJ-20190212-SD001.pdf>.
- NRDC, and National Consumer Law Center. 2022. “Water Affordability Advocacy Toolkit.” <https://www.nrdc.org/resources/water-affordability-advocacy-toolkit>.
- O’Donnell, Emerson, and Cynthia Koehler. 2024. “WaterNow’s 2024 Emerging Leader Program: Supporting Changemakers.” WaterNow Alliance. April 30, 2024. <https://waternow.org/2024/04/30/waternows-2024-emerging-leaders-diverse-dedicated-driven-changemakers/>.
- Office of Management and Budget. 2025. “OMB Memo M-25-11.” *The White House* (blog). January 21, 2025. <https://www.whitehouse.gov/briefings-statements/2025/01/omb-memo-m-25-11/>.
- Oklahoma Water Resources Board. 2024. “Funding Agency Coordinating Team.” Oklahoma Water Resources Board. 2024. <https://oklahoma.gov/owrb/financing/funding-agency-coordinating-team.html>.
- _____. n.d.-a. “Our Funding Programs.” Accessed March 27, 2025. <https://www.owrbbonds.com/oklahoma-water-resources-board-bonds-ok/additional-info/i2516?i=2>.
- _____. n.d.-b. “Rural Economic Action Plan Grants.” Accessed May 23, 2025. <https://oklahoma.gov/owrb/financing/rural-economic-action-plan-grants.html>.
- Olazabal, Marta, Ibon Galarraga, James Ford, Alexandra Lesnikowski, and Elisa Sainz de Murieta. 2017. “Towards Successful Adaptation: A Checklist for the Development of Climate Change Adaptation Plans.” *Working Papers*, January. <https://ideas.repec.org/p/bcc/wpaper/2017-01.html>.
- Oral, Hasan Volkan, Pedro Carvalho, Magdalena Gajewska, Nadia Ursino, Fabio Masi, Eric D. Van Hullebusch, Jan K. Kazak, et al. 2020. “A Review of Nature-Based Solutions for Urban Water Management in European Circular Cities: A Critical Assessment Based on Case Studies and Literature.” *Blue-Green Systems* 2 (1): 112–36. <https://doi.org/10.2166/bgs.2020.932>.
- Oregon State University. 2018. “Big Wood Basin Alternative Futures.” Climate Impacts Research Consortium. May 8, 2018. <https://pnwcirc.org/big-wood-basin-alternative-futures>.
- Oregon Water Resources Department. 2023. “State Drought Declaration Process & Emergency Tools.” <https://www.oregon.gov/owrd/programs/climate/droughtwatch/Documents/2023%20Drought%20Process%20and%20Tools.pdf>.

- Ortiz-Partida, J. Pablo, Coreen Weintraub, Angel S. Fernandez-Bou, and L. Maskey Mahesh. 2020. "Climate Change in the San Joaquin Valley: A Household and Community Guide to Taking Action." Cambridge, MA: Union of Concerned Scientists.
<https://www.ucsusa.org/resources/climate-change-san-joaquin-valley>.
- Pacific Institute. 2021. "Water Resilience: Definitions, Characteristics, Relationships to Existing Concepts, and Call to Action for Building a Water Resilient Future." <https://pacinst.org/wp-content/uploads/2021/10/Water-Resilience-Issue-Brief-Pacific-Institute-Oct-2021.pdf>.
- _____. 2023. "Climate Change and Flooding in Central Appalachia." Issue Brief.
https://pacinst.org/wp-content/uploads/1989/11/Central-Appalachia-Issue-Brief_Final.pdf.
- _____. n.d. "Water and Climate Equity in Rural Communities in the United States." Pacific Institute. Accessed January 6, 2025. <https://pacinst.org/water-and-climate-equity-in-rural-communities-in-the-united-states/>.
- Pacific Institute, and Alliance for Water Efficiency. 2012. "Water Rates: Water Demand Forecasting." Issue Brief. <https://pacinst.org/publication/water-rates-water-demand-forecasting-need-to-know-brief/>.
- Pacific Institute, and Community Water Center. 2012. "Water Rates: Water Affordability." Issue Brief. Oakland, CA: Pacific Institute. <https://pacinst.org/wp-content/uploads/2018/08/water-rates-affordability.pdf>.
- Pacific Institute, and DigDeep. 2024. "Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States in the Water, Sanitation, and Climate Change in the US Series, Part 1." Oakland, CA: Pacific Institute.
<https://pacinst.org/publication/water-sanitation-climate-change-us-part-1/>.
- Paul, Jonathan D., Wouter Buytaert, Simon Allen, Juan A. Ballesteros-Cánovas, Jagat Bhusal, Katarzyna Cieslik, Julian Clark, et al. 2018. "Citizen Science for Hydrological Risk Reduction and Resilience Building." *WIREs Water* 5 (1): e1262. <https://doi.org/10.1002/wat2.1262>.
- Pauloo, R. A., A. Escrivá-Bou, H. Dahlke, A. Fencl, H. Guillon, and G. E. Fogg. 2020. "Domestic Well Vulnerability to Drought Duration and Unsustainable Groundwater Management in California's Central Valley." *Environmental Research Letters* 15 (4): 044010.
<https://doi.org/10.1088/1748-9326/ab6f10>.
- Payton, E.A., A.O. Pinson, T. Asefa, L.E. Condon, L.-A.L. Dupigny-Giroux, B.L. Harding, J. Kiang, D.H. Lee, S.A. McAfee, J.M. Pflug, I. Rangwala, H.J. Tanana, and D.B. Wright, 2023: Ch. 4. Water. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.
<https://web.archive.org/web/20250629220617/https://nca2023.globalchange.gov/chapter/4>.

- Payton Scally, Corianne, Rebecca Marx, Ines Polonius, and Alison Davis. 2021. “Preparing Rural Water Systems for Extreme Weather and Climate Disasters: Lessons from South Texas and Winter Storm Uri.” Issue Brief. Urban Institute.
<https://www.urban.org/research/publication/preparing-rural-water-systems-extreme-weather-and-climate-disasters>.
- Pennsylvania Department of Environmental Protection. n.d. “PA DEP Small Drinking Water Systems Engineering Services Program Case Study.” Pennsylvania Department of Environmental Protection. Accessed January 31, 2025.
https://files.dep.state.pa.us/water/Drinking%20Water%20and%20Facility%20Regulation/lib/watersupply/oak_hall__case_study.pdf.
- Perrone, D, and S Jasechko. 2017. “Dry Groundwater Wells in the Western United States.” *Environmental Research Letters* 12 (10): 104002. <https://doi.org/10.1088/1748-9326/aa8ac0>.
- Phillis, Michael, and John Flesher. 2022. “Climate-Driven Flooding Poses Well Water Contamination Risks.” *AP News*, June 8, 2022. <https://apnews.com/article/climate-floods-storms-politics-health-2b0f09ecd8a836c9b7fe1fc7448e2470>.
- Pierce, Gregory, Ahmed Rachid El-Khattabi, Kyra Gmoser-Daskalakis, and Nicholas Chow. 2021. “Solutions to the Problem of Drinking Water Service Affordability: A Review of the Evidence.” *WIREs Water* 8 (4): e1522. <https://doi.org/10.1002/wat2.1522>.
- Poole, Brad. 2023. “Extension Collaboration to Help Farmers, Ranchers Save Water.” Arizona Cooperative Extension News. April 5, 2023. <https://extension.arizona.edu/news/extension-collaboration-help-farmers-ranchers-save-water>.
- Porse, Erik, Caitlyn Leo, Erick Eschker, Harold Leverenz, Jonathan Kaplan, John Johnston, Dakota Keene, and David Babchanik. 2023. “Adapting Wastewater Management Systems in California for Water Conservation and Climate Change.” *Sustainable and Resilient Infrastructure* 8 (4): 437–50. <https://doi.org/10.1080/23789689.2023.2180251>.
- Powers, Susan E., Jan E. DeWaters, and Suresh Dhaniyala. 2021. “Climate Literacy—Imperative Competencies for Tomorrow’s Engineers.” *Sustainability* 13 (17): 9684. <https://doi.org/10.3390/su13179684>.
- PrivateWellClass.org. n.d. “Have Questions about Your Well?” The Private Well Class. Accessed April 21, 2025. <https://privatewellclass.org/>.
- Proctor, Caitlin R., Juneseok Lee, David Yu, Amisha D. Shah, and Andrew J. Whelton. 2020. “Wildfire Caused Widespread Drinking Water Distribution Network Contamination.” *AWWA Water Science* 2 (4): e1183. <https://doi.org/10.1002/aws2.1183>.
- Purata, Valeria Lopez Portillo, Sarai Eunice Rodríguez, and Rebeca Lomelí. 2023. “Community Lessons for Successful Nature-Based Solutions Implementation.” October 4, 2023. <https://www.wri.org/update/community-lessons-successful-nature-based-solutions-implementation>.

- Ramanadhan, Shoba, Kayoll Galbraith-Gyan, Anna Revette, Alisa Foti, Charlotte Rackard James, Vilma Martinez-Dominguez, Elecia Miller, et al. 2021. “Key Considerations for Designing Capacity-Building Interventions to Support Evidence-Based Programming in Underserved Communities: A Qualitative Exploration.” *Translational Behavioral Medicine* 11 (2): 452–61. <https://doi.org/10.1093/tbm/ibz177>.
- Ramírez-Agudelo, Nancy Andrea, Roger Porcar Anento, Miriam Villares, and Elisabet Roca. 2020. “Nature-Based Solutions for Water Management in Peri-Urban Areas: Barriers and Lessons Learned from Implementation Experiences.” *Sustainability* 12 (23): 9799. <https://doi.org/10.3390/su12239799>.
- Randall, Laura. 2024. “Empowering Voices in Rural Communities: Supporting Inclusive Community Engagement for Water Decision-Making | AZ Water Innovation Initiative.” 2024. <https://azwaterinnovation.asu.edu/empowering-voices-rural-communities-supporting-inclusive-community-engagement-water-decision-making>.
- Ransom, Asm. Rhodesia. 2025. *Water Rate Assistance Program*. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202520260AB532#99INT.
- Raymond, Christopher M., Niki Frantzeskaki, Nadja Kabisch, Pam Berry, Margaretha Breil, Mihai Razvan Nita, Davide Geneletti, and Carlo Calfapietra. 2017. “A Framework for Assessing and Implementing the Co-Benefits of Nature-Based Solutions in Urban Areas.” *Environmental Science & Policy* 77 (November):15–24. <https://doi.org/10.1016/j.envsci.2017.07.008>.
- RCAC. 2023. “New Mexico’s Water Infrastructure Gets Big Boost with Landmark Resiliency & Regionalization Act.” RCAC (blog). March 20, 2023. <https://www.rcac.org/press-release/new-mexicos-water-infrastructure-gets-big-boost-with-landmark-resiliency-regionalization-act/>.
- REAL-Water. 2022. “Technological Innovations for Rural Water Supply in Low-Resource Settings.” United States Agency for International Development (USAID) Rural Evidence and Learning for Water Project. https://www.globalwaters.org/sites/default/files/4dec_technological_innovations.pdf.
- Resilient Rural America Project. n.d. “Resilient Rural America Project.” Accessed January 9, 2025. <https://resilientruralamerica.org/>.
- Resource Central. n.d. “Resource Central.” Resource Central. Accessed December 11, 2024. <https://resourcecentral.org/>.
- Reynolds, Koni. 2024. Emergency Community Water Assistance Grant Program. Interview by Morgan Shimabuku. Teams meeting.
- Ribot, Jesse. 2010. “Vulnerability Does Not Fall from the Sky: Toward Multiscale, pro-Poor Climate Policy.” In *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*, by Robin Mearns and Andrew Norton. DC: World Bank. <https://openknowledge.worldbank.org/handle/10986/2689>.

- Rigolon, Alessandro. 2024. "Great Parks Should Not Uproot Communities: Green Gentrification Risk Factors and Anti-Displacement Options." Trust for Public Land.
https://www.tpl.org/wp-content/uploads/2024/08/081224_Green-Papers_Great-Parks_G_final.pdf.
- River Network. 2021. "Equitable Water Infrastructure Toolkit."
<https://www.rivernetwork.org/connect-learn/resources/equitable-infrastructure-toolkit/>.
- _____. 2022. "The Clean Water Act Owner's Manual." 3rd Edition. The River Network.
<https://www.rivernetwork.org/connect-learn/resources/clean-water-act-owners-manual/>.
- _____. 2024. "Community-Centered Solutions for Green Gentrification and Displacement: Introducing a New Equitable Development Toolkit."
<https://www.rivernetwork.org/community-centered-solutions-for-green-gentrification-and-displacement/>.
- _____. n.d. "Tools for Equitable Climate Resilience." Accessed April 22, 2025.
<https://www.rivernetwork.org/connect-learn/resources/clrtoolkit/>.
- River Network, and WaterNow Alliance. 2021. "Building Blocks of Trust: Creating Authentic and Equitable Relationships Between Community Organizations and Water Utilities."
<https://www.rivernetwork.org/wp-content/uploads/2021/11/buildingblocksoftrust-r3.pdf>.
- Robbins, Jim. 2025. "How Climate Change Puts the Safety of Drinking Water at Risk." Yale E360. 2025. <https://e360.yale.edu/features/climate-change-drinking-water>.
- Roller, Zoë, Stephen Gasteyer, Nora Nelson, WenHua Lai, and Marie Carmen Shinge. 2019. "Closing The Water Access Gap In The United States: A National Action Plan." Dig Deep and U.S. Water Alliance. <https://www.digdeep.org/close-the-water-gap>.
- Rosen, Rudolph A., Luis A. Cifuentes, James Fischer, Howard Marquise, and John C. Tracy. 2018. "Water Security for Texas: A Post-Secondary Education Pathway for Water Workforce Readiness." *Texas Water Journal* 9 (1): 120–28. <https://twj-ojs-tdl.tdl.org/twj/article/view/7078/6209>.
- Rowe, Amy, and Michele Bakacs. 2012. "An Introduction to Green Infrastructure Practices." Fact Sheet Cooperative Extension Fact Sheet FS1197. New Brunswick, NJ: Rutgers University.
<https://njaes.rutgers.edu/fs1197/>.
- Roy, Allison H., Seth J. Wenger, Tim D. Fletcher, Christopher J. Walsh, Anthony R. Ladson, William D. Shuster, Hale W. Thurston, and Rebekah R. Brown. 2008. "Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States." *Environmental Management* 42 (2): 344–59.
<https://doi.org/10.1007/s00267-008-9119-1>.
- Rural Community Assistance Corporation. 2021. "Regionalization." September 21, 2021.
<https://www.rcap.org/special-initiatives/regionalization/>.

- Rural Community Assistance Partnership. 2019. “Fiscal Year 2019 Annual Report: Expanding Impact for Rural Quality of Life.” https://www.rcap.org/wp-content/uploads/2020/02/RCAP_AnnualReport-2.pdf.
- _____. 2020. “Resiliency through Water and Wastewater System Partnerships.” Rural Community Assistance Partnership. https://rcap.org/wp-content/uploads/2021/09/RCAP-Regionalization-Research-Report_March-2020_Pages-1.pdf.
- _____. 2021a. “Formulate Great Rates: The Guide to Conducting a Rate Study for a Small System.” https://rcap.org/wp-content/uploads/2021/11/RCAP_RatesGuide-2021-FIN-LO-1.pdf.
- _____. 2021b. “Rate Setting & Affordability.” RCAP. November 19, 2021. <https://www.rcap.org/managerialfinancialhub/rate-setting-affordability/>.
- _____. 2022. “The Basics of Financial Management for Small Community Utilities.” https://www.rcap.org/wp-content/uploads/2022/11/flip_Financial-Management-Guide.pdf.
- _____. 2024. “Asset Management Guide for Small Drinking Water and Wastewater Systems.” <https://www.rcap.org/wp-content/uploads/2024/09/RCAP-Asset-Management-Guidebook-2024.pdf>.
- _____. n.d.-a. “Environmental Programs.” Rcap.Org. Accessed September 27, 2024. <https://www.rcap.org/environmental-programs/>.
- _____. n.d.-b. “RCAP Private Well Program Brochure.” RCAP. Accessed September 13, 2024. <https://www.rcap.org/wp-content/uploads/2024/05/Private-Wells-One-Pager-v2.pdf>.
- _____. n.d.-c. “Security, Resiliency & Emergency Response Planning.” Accessed December 20, 2024. <https://www.rcap.org/managerialfinancialhub/security-resiliency-emergency-response-planning/>.
- Rural Health Information Hub. n.d.-a. “Rural Barriers to Emergency Preparedness and Response - RHInfo Toolkit.” Accessed August 18, 2024. <https://www.ruralhealthinfo.org/toolkits/emergency-preparedness/1/rural-barriers>.
- _____. n.d.-b. “What Is Rural?” Accessed February 4, 2025. <https://www.ruralhealthinfo.org/topics/what-is-rural>.
- Scanlan, Melissa K., and Misbah Husain. 2022. “Disadvantaged Communities, Water Justice & The Promise of The Infrastructure Investment and Jobs Act.” *SSRN*, June. <https://papers.ssrn.com/abstract=4128452>.
- Schipper, E. Lisa F. 2020. “Maladaptation: When Adaptation to Climate Change Goes Very Wrong.” *One Earth* 3 (4): 409–14. <https://doi.org/10.1016/j.oneear.2020.09.014>.
- Schmitt, Katlyn, Darya Minovi, Sophie Loeb, and Mary H. Ward. 2024. “A State-By-State Comparison of Policies That Protect Private Well Users.” *Journal of Exposure Science & Environmental Epidemiology* 34 (1): 155–60. <https://doi.org/10.1038/s41370-024-00645-2>.

- Schreiner, Bruce, and Kristin Hall. 2025. “Rivers Flood in US South after Heavy Rains.” *AP News*, 2025. <https://apnews.com/article/severe-weather-flooding-tornado-cda0e8803e4e692d162de856ccc6ef9e>.
- Schwing, Emily. 2025. “Newtok, Alaska, Was Supposed to Be a Model for Climate Relocation. Here’s How It Went Wrong.” *KYUK*, May 29, 2025. <https://www.kyuk.org/science-and-environment/2025-05-29/newtok-was-supposed-to-be-a-model-for-climate-relocation-heres-how-it-went-wrong>.
- Self-Help Enterprises. n.d. “Community Development.” Self-Help Enterprises. Accessed April 18, 2025. <https://www.selfhelpenterprises.org/programs/community-development/>.
- Semuels, Alana. 2019. “‘They’re Trying to Wipe Us Off the Map.’ Why Independent Farming in America Is Close to Extinction.” *TIME*. November 27, 2019. <https://time.com/5736789/small-american-farmers-debt-crisis-extinction/>.
- SERCAP News. 2022. “SERCAP’s Certified CDFI Loan Fund Assists Low-Income Couple in City of Martinsville, Virginia.” *SERCAP (blog)*. October 21, 2022. <https://www.sercap.org/blog-news/sercaps-certified-cdfi-loan-fund-assists-low-income-couple-city-martinsville-virginia>.
- Shakesprere, Jessica, Matthew Mizota, Rod Martinez, Hannah Daly, and Elsa Falkenburger. 2021. “Fostering Partnerships for Community Engagement.” Urban Institute. https://www.urban.org/sites/default/files/publication/104935/fostering-partnerships-for-community-engagement_0.pdf.
- Shimabuku, Morgan, and Jessi Snyder. 2022. “Ensuring Water Conservation and Efficiency Programs Are Accessible to All—In California and Beyond.” *Pacific Institute (blog)*. July 5, 2022. <https://pacinst.org/water-conservation-efficiency-accessibility/>.
- Shore, Derek. 2025. “Keeping a Community Flowing: How Maple Creek Farms Is Overcoming Infrastructure Challenges with CU’s Support.” *Communities Unlimited (blog)*. March 20, 2025. <https://communitiesu.org/blog/2025/03/20/keeping-a-community-flowing/>.
- Siirila-Woodburn, Erica R., Alan M. Rhoades, Benjamin J. Hatchett, Laurie S. Huning, Julia Szinai, Christina Tague, Peter S. Nico, et al. 2021. “A Low-to-No Snow Future and Its Impacts on Water Resources in the Western United States.” *Nature Reviews Earth & Environment* 2 (11): 800–819. <https://doi.org/10.1038/s43017-021-00219-y>.
- Simons, Elise J. 2017. “Exploring Roles for Communities in Green Infrastructure Projects.” Master of Arts, Medford, MA: Tufts University. <https://www.12000raingardens.org/wp-content/uploads/2015/10/Exploring-Roles-for-Communities-in-Green-Infrastructure-Projects-SimonsGIThesis.pdf>.

- Simonson, Emily. 2022. "Centering Water Equity in Capital Projects: Applying Equitable Infrastructure Principles Across the Infrastructure Cycle." *US Water Alliance Blog* (blog). April 1, 2022. <https://web.archive.org/web/20230311143840/http://uswateralliance.org/resources/blog/centering-water-equity-capital-projects-applying-equitable-infrastructure-principles>.
- Simpson, Leanne R. 2004. "Anticolonial Strategies for the Recovery and Maintenance of Indigenous Knowledge." *American Indian Quarterly* 28 (3/4): 373–84. <https://www.jstor.org/stable/4138923>.
- Skeptical Science. n.d. "Global Warming and Climate Change Skepticism Examined." Skeptical Science. Accessed March 28, 2025. <https://skepticalscience.com/>.
- Sledge, Daniel, and Herschel F. Thomas. 2019. "From Disaster Response to Community Recovery: Nongovernmental Entities, Government, and Public Health." *American Journal of Public Health* 109 (3): 437–44. <https://doi.org/10.2105/AJPH.2018.304895>.
- Smith, Kris. 2021. "New Program to Reduce Flood Risk in Rural Communities: Pilot Project in Three Forks, MT." Headwaters Economics. February 11, 2021. <https://headwaterseconomics.org/natural-hazards/three-forks-mt-decreasing-flood-risk/>.
- _____. 2023. "Match Requirements Prevent Rural and Low-Capacity Communities from Accessing Climate Resilience Funding." *Headwaters Economics* (blog). January 13, 2023. <https://headwaterseconomics.org/equity/match-requirements/>.
- Smith, Kris, Annie Bennett, Diana Schoder, and Damian Shapes Padilla. 2023. "Decreasing Flood Risk in the Midwest with Regional Collaborations." Washington D.C.: Headwaters Economics, Georgetown Climate Center. <https://headwaterseconomics.org/natural-hazards/decreasing-flood-risk/>.
- Smith, Mia. 2024. "Journey towards Water Security." Forest Trends. <https://www.forest-trends.org/wp-content/uploads/2024/04/Journey-Towards-02.04-2.pdf>.
- Sohns, Antonia. 2023. "Differential Exposure to Drinking Water Contaminants in North Carolina: Evidence from Structural Topic Modeling and Water Quality Data." *Journal of Environmental Management* 336 (June):117600. <https://doi.org/10.1016/j.jenvman.2023.117600>.
- Solheim, Anders, Vittoria Capobianco, Amy Oen, Bjørn Kalsnes, Turid Wulff-Knutsen, Mari Olsen, Nicola Del Seppia, Idoia Arauzo, Eva Garcia Balaguer, and James Michael Strout. 2021. "Implementing Nature-Based Solutions in Rural Landscapes: Barriers Experienced in the PHUSICOS Project." *Sustainability* 13 (3): 1461. <https://doi.org/10.3390/su13031461>.
- Solis, Miriam. 2018. "Engineering Justice: Cities, Race, and 21st Century Wastewater Infrastructure." UC Berkeley. <https://escholarship.org/uc/item/2f8703sw>.

- _____. 2023. “Conditions and Consequences of ELULU Improvement: Environmental Justice Lessons from San Francisco, CA.” *Journal of Planning Education and Research* 43 (4): 1007–19. <https://doi.org/10.1177/0739456X20929407>.
- Source Water Collaborative. n.d. “Source Water Collaborative.” Accessed April 21, 2025. <https://www.sourcewatercollaborative.org/>.
- Southern Plains Climate Hub. n.d. “Rainwater Harvesting: A Tribal Partnership Project.” US Department of Agriculture. Accessed September 18, 2024. <https://www.climatehubs.usda.gov/hubs/southern-plains/topic/rainwater-harvesting-tribal-partnership-project>.
- Southwest Basins Roundtable. 2022. “Southwest Basin Implementation Plan.” <https://swbasinsroundtable.org/southwest-basin-implementation-plan/volume-1/>.
- Spearman, Margaret, and Heather McGray. 2011. “Making Adaptation Count: Concepts and Options for Monitoring and Evaluation of Climate Change Adaptation.” World Resources Institute. http://pdf.wri.org/making_adaptation_count.pdf.
- Spurlock, Shannon, Angela Davis, and Rabia Chaudhry. 2023. “Lessons for Optimizing the Adoption of Water Reuse in Underserved Communities: An Output of the National Water Reuse Action Plan (WRAP) Action 8.5.” EPA-820-R-23-007. US Environmental Protection Agency. <https://www.epa.gov/system/files/documents/2023-07/Action%208.5%20Milestone%209%20Lessons%20for%20Optimizing%20the%20Adoption%20of%20Water%20Reuse%20in%20Underserved%20Communities.pdf>.
- State of Louisiana. 2017. “Louisiana’s Comprehensive Master Plan for a Sustainable Coast.” https://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Book_CFinal-with-Effective-Date-06092017.pdf.
- Statman-Weil, Zoe, Leora Nanus, and Nancy Wilkinson. 2020. “Disparities in Community Water System Compliance with the Safe Drinking Water Act.” *Applied Geography* 121 (August):102264. <https://doi.org/10.1016/j.apgeog.2020.102264>.
- Status of Tribes and Climate Change Working Group. 2021. “The Status of Tribes and Climate Change Report.” Flagstaff, AZ: Institute for Tribal Environmental Professionals, Northern Arizona University. <http://nau.edu/stacc2021>.
- _____. 2025. “Status of Tribes and Climate Change, Vol. 2.” Northern Arizona University: Institute for Tribal Environmental Professionals. <https://sites.google.com/view/staccreport>.
- Stein, Kathryn M. 2020. “An Artist and Educator Captures Deeply Personal Stories of Life without Clean Water.” *The Confluence, University of California Ag & Natural Resources* (blog). October 19, 2020. <https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=43982>.

- Sternlieb, Faith, R. Patrick Bixler, Heidi Huber-Stearns, and Ch'aska Huayhuaca. 2013. "A Question of Fit: Reflections on Boundaries, Organizations and Social–Ecological Systems." *Journal of Environmental Management* 130 (November):117–25. <https://doi.org/10.1016/j.jenvman.2013.08.053>.
- Stockholm Environment Institute, Michael Boyland, Heidi Tuhkanen, Jonathan Green, and Karina Barquet. 2022. "Principles for Just and Equitable Nature-Based Solutions." Stockholm Environment Institute. <https://doi.org/10.51414/sei2022.016>.
- Stockholm International Water Institute. 2020. "Principles and Practices of Integrated Water Resources Management Workplace-Based Professional Training." https://siwi.org/wp-content/uploads/2020/06/IWRM_Manual1_final.pdf.
- Storey, Brett, Andy Fecko, Elena DeLacy, David Edelson, Michael Woodbridge, Roger Bales, and Andy Fritensky. 2019a. "French Meadows Forest Restoration Project." <https://www.nature.org/content/dam/tnc/nature/en/photos/f/m/FMPFactsheet2-27-19final.pdf>.
- Stults, M., S. Petersen, W. Baule, E. Nasser, E. Gibbons, and M. Fougerat. 2016. "Climate Change Vulnerability Assessment and Adaptation Plan: 1854 Ceded Territory Including the Bois Forte, Fond Du Lac, and Grand Portage Reservation." Duluth, MN: 1854 Ceded Territory. <https://glisa.umich.edu/publication/climate-change-vulnerability-assessment-and-adaptation-plan-1854-ceded-territory-including-the-bois-forte-fond-du-lac-and-grand-portage-reservations/>.
- Sustainable Conservation. n.d. "Managing Dairy Manure for Clean Water." Sustainable Conservation. Accessed October 3, 2024. <https://suscon.org/project/waste-not/>.
- Szinai, Julia, Sonali Abraham, Heather Cooley, and Peter H. Gleick. 2021. "The Future of California's Water-Energy-Climate Nexus." Pacific Institute. https://pacinst.org/wp-content/uploads/2021/09/Water-Energy-Report_Sept-2021.pdf.
- Taylor, Betsy, Shannon McNeeley, Maria Gaglia-Bareli, Laura Landes, Lena Schlichting, Deborah Thompson, and Rachel Will. 2024. "Water and Climate Equity in Rural Water Systems in the United States." Pacific Institute, LiKEN, RCAP. <https://pacinst.org/publication/water-and-climate-equity-in-rural-water-systems-in-the-united-states/>.
- Teodoro, Manuel P. 2018. "Measuring Household Affordability for Water and Sewer Utilities." *Journal - American Water Works Association* 110 (1): 13–24. <https://doi.org/10.5942/jawwa.2018.110.0002>.
- _____. 2019. "Water and Sewer Affordability in the United States." *AWWA Water Science* 1 (2): e1129. <https://doi.org/10.1002/aws2.1129>.
- Teodoro, Manuel P., and Ryan Thiele. 2024. "Water and Sewer Price and Affordability Trends in the United States, 2017–2023." *American Water Works Association* 116 (7): 14–24. <https://doi.org/10.1002/awwa.2315>.

- The Blackbelt Unincorporated Wastewater Program. n.d. “The Blackbelt Unincorporated Wastewater Program.” Accessed January 14, 2025. <https://www.bbuwp.org/>.
- The Center for Water Security and Cooperation. n.d. “Water Access and Equity Lab.” Cwsc. Accessed April 18, 2025. <https://www.ourwatersecurity.org/waterlab>.
- The Nature Conservancy. 2020. “Natural Infrastructure.” April 5, 2020. <https://www.nature.org/en-us/about-us/who-we-are/how-we-work/policy/natural-infrastructure/>.
- _____. 2021. “Large-Scale Levee Setback Playbook.” St. Louis, Missouri. https://www.nature.org/content/dam/tnc/nature/en/documents/MOLeveeSetbackPlaybook_singlepages-complete.pdf.
- _____. n.d.-a. “Places We Protect: Verde River, Arizona.” *The Nature Conservancy* (blog). Accessed April 18, 2025. <https://www.nature.org/en-us/get-involved/how-to-help/places-we-protect/verde-river/>.
- _____. n.d.-b. “WaterProof.” Accessed April 23, 2025. <https://water-proof.org/learning/>.
- The White House. 2022. *Building a Better America: A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners*. Washington D.C. <https://web.archive.org/web/20250111211211/https://www.whitehouse.gov/wp-content/uploads/2022/05/BUILDING-A-BETTER-AMERICA-V2.pdf#page=226>.
- _____. 2025. “Executive Order Initial Rescissions Of Harmful Executive Orders And Actions.” <https://www.whitehouse.gov/presidential-actions/2025/01/initial-rescissions-of-harmful-executive-orders-and-actions/>.
- Thomas, Kimberley, R. Dean Hardy, Heather Lazrus, Michael Mendez, Ben Orlove, Isabel Rivera-Collazo, J. Timmons Roberts, Marcy Rockman, Benjamin P. Warner, and Robert Winthrop. 2019. “Explaining Differential Vulnerability to Climate Change: A Social Science Review.” *WIREs Climate Change* 10 (2): e565. <https://doi.org/10.1002/wcc.565>.
- Tidwell, Vincent, Vanessa Vargas, Shannon Jones, Bern Dealy, Calvin Shaneyfelt, Braeton Smith, and Barbara Moreland. 2015. “Analysis of High Plains Resource Risk and Economic Impacts.” United States: US Department of Homeland Security. <https://doi.org/10.2172/1248575>.
- Tonn, Bruce, David Carroll, Erin Rose, Beth Hawkins, Scott Pigg, Daniel Bausch, Greg Dalhoff, et al. 2015. “Weatherization Works II – Summary of Findings From the ARRA Period Evaluation of the U.S. Department of Energy’s Weatherization Assistance Program.” ORNL/TM-2015/139. Oak Ridge National Laboratory. <https://www.energy.gov/sites/prod/files/2015/09/f26/weatherization-works-II-ARRA-period-eval.pdf>.

- Tonn, Bruce, Erin Rose, and Beth Hawkins. 2014. "Weatherization Beyond the Numbers: Case Studies of Fifteen High-Performing Weatherization Agencies - Conducted May 2011 through July 2012." ORNL/TM-2014/317. Oak Ridge National Laboratory.
https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNLTM-2014_317.pdf.
- Treen, Kathie M. d'I., Hywel T. P. Williams, and Saffron J. O'Neill. 2020. "Online Misinformation about Climate Change." *WIREs Climate Change* 11 (5): e665. <https://doi.org/10.1002/wcc.665>.
- Tribal Adaptation Menu Team. 2019. "Dibaginjigaadeg Anishinaabe Ezhitwaad: A Tribal Climate Adaptation Menu." Odanah, Wisconsin: Great Lakes Indian Fish and Wildlife Commission.
<https://glifwc.org/ClimateChange/TribalAdaptationMenuV1.pdf>.
- Turner, Nancy J., Marianne Boelscher Ignace, and Ronald Ignace. 2000. "Traditional Ecological Knowledge and Wisdom of Aboriginal Peoples in British Columbia." *Ecological Applications* 10 (5): 1275–87. [https://doi.org/10.1890/1051-0761\(2000\)010\[1275:TEKAWO\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2000)010[1275:TEKAWO]2.0.CO;2).
- Udall, Bradley, and Jonathan Overpeck. 2017. "The Twenty-First Century Colorado River Hot Drought and Implications for the Future." *Water Resources Research* 53 (3): 2404–18.
<https://doi.org/10.1002/2016WR019638>.
- United Nations. 2014. "The Human Right to Water and Sanitation." 2014.
https://www.un.org/waterforlifedecade/human_right_to_water.htm.
- United Nations Children's Fund, and Global Water Partnership. 2017. "WASH Climate Resilient Development: Monitoring and Evaluation for Climate Resilient WASH."
https://www.gwp.org/globalassets/global/about-gwp/publications/unicef-gwp/gwp_unicef_monitoring-and-evaluation-brief.pdf.
- United Nations Development Program. 2023. "Powerhouse for Strong Adaptation Systems: Monitoring, Evaluation and Learning." UNDP. 2023.
<https://www.undp.org/blog/powerhouse-strong-adaptation-systems-monitoring-evaluation-and-learning>.
- United Nations Environment Programme. 2017. "What Is Integrated Water Resources Management?" September 22, 2017. <https://www.unep.org/explore-topics/disasters-conflicts/where-we-work/sudan/what-integrated-water-resources-management>.
- United Nations Framework Convention on Climate Change. 1994. *United Nations Framework Convention on Climate Change: Article 1, Definitions*.
<https://unfccc.int/resource/ccsites/zimbab/conven/text/art01.htm>.
- _____. 2014. "Technologies for Adaptation in the Water Sector." TEC Brief #5.
https://unfccc.int/ttclear/misc/_/StaticFiles/gnwoerk_static/TEC_column_L/0cac6640a3b945c08e7a54f8e496223e/55e192e14cd6495f975f4098843baf7e.pdf.

- United Nations Framework Convention on Climate Change, Kyoto Protocol, and Paris Agreement. 2023. “Monitoring and Evaluation of Adaptation at the National and Subnational Levels: Technical Paper by the Adaptation Committee.” Germany. https://unfccc.int/sites/default/files/resource/AC_TechnicalPaper_AdaptationMandE_2023.pdf.
- United Way Worldwide. n.d. “Call 211 for Essential Community Services.” Accessed April 18, 2025. <http://www.211.org/>.
- University of Arizona Cooperative Extension. 2022. “Water Irrigation Efficiency Program.” The University of Arizona Cooperative Extension. August 23, 2022. <https://extension.arizona.edu/water-irrigation-efficiency-program>.
- University of Illinois at Urbana-Champaign. n.d.-a. “DecentralizedWastewater.Org.” Accessed April 18, 2025. <https://decentralizedwastewater.org/>.
- _____. n.d.-b. “PrivateWellClass.Org.” Accessed April 18, 2025. <https://privatewellclass.org/>.
- _____. n.d.-c. “WaterOperator.Org.” Accessed April 18, 2025. <https://wateroperator.org/>.
- University of New Mexico Southwest Environmental Finance Center. 2024. “Water Sector Interdependencies: Small and Medium-Sized System Guidance.” #5086B. The Water Research Foundation. <https://www.waterrf.org/research/projects/case-studies-water-sector-interdependencies>.
- UNL Water. 2025. “Registration Open for Nebraska Master Irrigator Design Summits.” 2025. <https://water.unl.edu/registration-open-nebraska-master-irrigator-design-summits/>.
- Urban Resources Initiative. 2016. “Green Infrastructure.” Urban Resources Initiative. June 14, 2016. <https://uri.yale.edu/programs/green-infrastructure>.
- US Census Bureau. 2022a. “Community Resilience Estimates.” 2022. <https://www.census.gov/programs-surveys/community-resilience-estimates.html>.
- _____. 2022b. “Nation’s Urban and Rural Populations Shift Following 2020 Census.” Census.Gov. 2022. <https://www.census.gov/newsroom/press-releases/2022/urban-rural-populations.html>.
- US Climate Resilience Toolkit. 2015. “Early Warning Information Increases Options for Drought Mitigation.” 2015. <https://toolkit.climate.gov/case-study/early-warning-information-increases-options-drought-mitigation>.
- _____. 2024. “Restoring Natural Dunes to Enhance Coastal Protection.” 2024. <https://toolkit.climate.gov/case-studies/restoring-natural-dunes-enhance-coastal-protection>.

- _____. n.d.-a. “Guidelines for Considering Traditional Knowledges in Climate Change Initiatives U.S. Climate Resilience Toolkit.” Accessed April 22, 2025. <https://toolkit.climate.gov/tool/guidelines-considering-traditional-knowledges-climate-change-initiatives>.
- _____. n.d.-b. “Home.” Accessed April 22, 2025. <https://toolkit.climate.gov/about-toolkit>.
- _____. n.d.-c. “Learn the Steps to Resilience.” Accessed March 4, 2025. <https://toolkit.climate.gov/overview-steps>.
- _____. n.d.-d. “Online Training for Water Utilities.” Accessed April 18, 2025. <https://toolkit.climate.gov/course/online-training-water-utilities-wuca>.
- US Department of Agriculture. 2014. “Rural Development Helps Restore Water Supply to Town of Gifford after Devastating Tornado.” April 14, 2014. <https://www.usda.gov/about-usda/news/blog/rural-development-helps-restore-water-supply-town-gifford-after-devastating-tornado>.
- _____. 2017. “Still Living Without the Basics in the 21st Century: Analyzing the Availability of Water and Sanitation Services in the United States.” Rural Community Assistance Partnership. <https://www.rcap.org/wp-content/uploads/2017/05/Still-Living-Without-the-Basics-Water.pdf>.
- _____. 2019. “Circuit Rider Program Technical Assistance for Rural Water Systems.” https://www.rd.usda.gov/files/RD_FS_RUS_CircuitRider_508.pdf.
- _____. 2023a. “Emergency Community Water Assistance Grants.” Rural Development. 2023. <https://www.rd.usda.gov/programs-services/water-environmental-programs/emergency-community-water-assistance-grants>.
- _____. 2023b. “Single Family Housing Repair Loans & Grants in Presidentially Declared Disasters.” USDA Rural Development. July 18, 2023. <https://web.archive.org/web/20250703012237/https://www.rd.usda.gov/programs-services/single-family-housing-programs/single-family-housing-repair-loans-grants-presidentially-declared-disasters>.
- _____. 2025a. “Population & Migration.” USDA Economic Research Service. 2025. <https://www.ers.usda.gov/topics/rural-economy-population/population-migration>.
- _____. 2025b. “Rural Poverty & Well-Being.” US County Poverty Rates , Average, Economic Research Service-. 2025. https://public.tableau.com/views/U_S_countypovertyrates/Povertydashboardorig?%3Aembed=y%3AapiID=embhost0%3AshowVizHome=n%3AapiInternalVersion=1.162.0%3AapiExternalVersion=3.11.0&navType=0&navSrc=Opt%3AdisableUrlActionsPopups=n%3Atabs=y%3Atoolbar=bottom%3Adevice=default&mobile=n%3AhideEditButton=n%3AhideEditInDesktopButton=n%3AsuppressDefaultEditBehavior=n%3Ajsdebug=n.

- _____. n.d.-a. “Circuit Rider Program - Technical Assistance for Rural Water Systems.” Rural Development. Accessed September 27, 2024. <https://www.rd.usda.gov/programs-services/water-environmental-programs/circuit-rider-program-technical-assistance-rural-water-systems>.
- _____. n.d.-b. “Ecosystem Services.” Climate Hubs. Accessed September 13, 2024. <https://www.climatehubs.usda.gov/ecosystem-services>.
- _____. n.d.-c. “‘Grassroots’ Source Water Protection Program.” Conservation Programs, Farm Service Agency. Accessed December 19, 2024. <https://www.fsa.usda.gov/programs-and-services/conservation-programs/source-water-protection>.
- _____. n.d.-d. “Rural Decentralized Water Systems Grant Program.” Water & Environmental Programs, Rural Development. Accessed March 31, 2025. <https://www.rd.usda.gov/programs-services/water-environmental-programs/rural-decentralized-water-systems-grant-program>.
- _____. n.d.-e. “Water & Environmental Programs.” Rural Development. Accessed January 14, 2025. <https://www.rd.usda.gov/programs-services/water-environmental-programs>.
- _____. n.d.-f. “Welcome to the USDA Climate Hubs.” Accessed January 8, 2025. <https://www.climatehubs.usda.gov/>.
- US Department of Energy. 2023. “Weatherization Assistance Program.” DOE/GO-102023-5897. State & Community Energy Programs. https://www.energy.gov/sites/default/files/2023-08/2023-WAP-Fact-Sheet_0.pdf.
- US Department of Health and Human Services. 2023. “RCD Program: Bringing Safe Water to Our Nation’s Communities.” Office of Community Services. April 24, 2023. <https://acf.gov/ocs/rural-community-development-program-impacts>.
- _____. 2025. “Low Income Household Water Assistance Program: Implementation and Impact Final Report.” Office of Community Services, Administration for Children & Families. <https://www.acf.hhs.gov/ocs/policy-guidance/lihwap-dcl-2025-01-ocs-releases-final-lihwap-implementation-impact-report>.
- US Department of Housing and Urban Development. n.d. “Community Development Block Grant Disaster Recovery Funds.” Accessed April 18, 2025. <https://www.hudexchange.info/programs/cdbg-dr>.
- US Department of the Interior, US Department of Commerce, and National Marine Fisheries Service. 2013. “Klamath Dam Removal Overview Report for the Secretary of the Interior: An Assessment of Science and Technical Information.” <https://klamathrenewal.org/wp-content/uploads/2020/07/A7-Full-SDOR-accessible-022216.pdf>.
- US Drought Monitor. n.d. “Current Map.” Accessed March 21, 2025. <https://droughtmonitor.unl.edu/>.

- US Environmental Protection Agency. 2002. "Kentucky Straight Pipes Report Harlan, Martin, and Bath Counties." US EPA, Region 4. <https://www.epa.gov/sites/default/files/2015-06/documents/2002-1107.pdf>.
- _____. 2011. "National Characteristics of Drinking Water Systems Serving 10,000 or Fewer People." EPA 816-R-10-022. U.S. EPA. <https://www.epa.gov/sites/default/files/2015-12/documents/epa816r10022.pdf>.
- _____. 2014a. "Emergency Response for Drinking Water and Wastewater Utilities." Collections and Lists. October 7, 2014. <https://www.epa.gov/waterutilityresponse>.
- _____. 2014b. "Promoting Technology Innovation for Clean and Safe Water Water Technology Innovation Blueprint—Version 2." https://19january2017snapshot.epa.gov/sites/production/files/2014-04/documents/clean_water_blueprint_final.pdf.
- _____. 2015a. "About Small Wastewater Systems." Overviews and Factsheets. Office of Water. January 7, 2015. <https://www.epa.gov/small-and-rural-wastewater-systems/about-small-wastewater-systems>.
- _____. 2015b. "Basic Information about Source Water Protection." Overviews and Factsheets. Source Water Protection (SWP), Office of Ground Water and Drinking Water. March 27, 2015. <https://www.epa.gov/sourcewaterprotection/basic-information-about-source-water-protection>.
- _____. 2015c. "Incident Action Checklists for Water Utilities." Collections and Lists. June 9, 2015. <https://www.epa.gov/waterutilityresponse/incident-action-checklists-water-utilities>.
- _____. 2015d. "Information about Public Water Systems." Office of Water. <https://www.epa.gov/dwreginfo/information-about-public-water-systems>.
- _____. 2015e. "Learn about Capacity Development." Building the Capacity of Drinking Water Systems, Office of Ground Water and Drinking Water. April 21, 2015. <https://www.epa.gov/dwcapacity/learn-about-capacity-development>.
- _____. 2015f. "Mutual Aid and Assistance for Drinking Water and Wastewater Utilities." Overviews and Factsheets. March 31, 2015. <https://www.epa.gov/waterutilityresponse/mutual-aid-and-assistance-drinking-water-and-wastewater-utilities>.
- _____. 2015g. "Private Drinking Water Well Programs in Your State." Office of Water. 2015. <https://www.epa.gov/privatewells/private-drinking-water-well-programs-your-state>.
- _____. 2015h. "Small Drinking Water System Variances." Overviews and Factsheets. Office of Water. September 23, 2015. <https://www.epa.gov/sdwa/small-drinking-water-system-variances>.

- _____. 2015i. “Technical, Managerial and Financial (TMF) Capacity Resources for Small Drinking Water Systems.” Building the Capacity of Drinking Water Systems, Office of Ground Water and Drinking Water. April 21, 2015. <https://www.epa.gov/dwcapacity/technical-managerial-and-financial-tmf-capacity-resources-small-drinking-water-systems>.
- _____. 2015j. “Vulnerability Self-Assessment Tool: Conduct a Drinking Water or Wastewater Utility Risk Assessment.” Data and Tools. Water Resilience, Office of Water. April 16, 2015. <https://www.epa.gov/waterresilience/vulnerability-self-assessment-tool-conduct-drinking-water-or-wastewater-utility>.
- _____. 2016. “Fredericktown, Missouri Prepares for Climate Change Drought Risk.” Missouri. April 14, 2016. <https://www.epa.gov/arc-x/fredericktown-missouri-prepares-climate-change-drought-risk>.
- _____. 2019a. “Quality Assurance Handbook and Toolkit for Participatory Science Projects.” Data and Tools. February 28, 2019. <https://www.epa.gov/participatory-science/quality-assurance-handbook-and-toolkit-participatory-science-projects>.
- _____. 2019b. “Water Reuse Action Plan.” Office of Water. Water Reuse. February 19, 2019. <https://www.epa.gov/waterreuse/water-reuse-action-plan>.
- _____. 2020. “Small System Risk and Resilience Assessment Checklist.” Other Policies and Guidance. Water Resilience, Office of Water. May 12, 2020. <https://www.epa.gov/waterresilience/small-system-risk-and-resilience-assessment-checklist>.
- _____. 2021a. “Addressing Contamination of Drinking Water Distribution Systems from Volatile Organic Compounds (VOCs) After Wildfires.” Office of Water. https://www.epa.gov/system/files/documents/2021-09/addressing-contamination-of-drinking-water-distribution-systems-from-volatile-organic-compounds-after-wildfires_508.pdf.
- _____. 2021b. “City of Fredericktown, Missouri.” Case Study: Water and Wastewater Utilities Planning for Resilience. Office of Water. <https://www.epa.gov/crwu/adaptation-case-studies-water-utilities>.
- _____. 2021c. “Report to Congress on The Prevalence Throughout the U.S. of Low- and Moderate-Income Households Without Access to a Treatment Works and The Use by States of Assistance under Section 603(c)(12) of the Federal Water Pollution Control Act.” Office of Water. https://www.epa.gov/system/files/documents/2022-01/low-mod-income-without-treatment_report-to-congress.pdf.
- _____. 2021d. “Sewer Overflow and Stormwater Reuse Municipal Grants Program: Grant Implementation Document.” US EPA, Office of Water. https://www.epa.gov/sites/default/files/2021-03/documents/osg_program_implementation_document.pdf.

- _____. 2022a. “Asset Management: A Handbook for Small Water Systems.” https://www.epa.gov/system/files/documents/2022-06/FINAL%20AM%20Handbook%20for%20Small%20Water%20Systems%20STEP%20Guide_508.pdf.
- _____. 2022b. “Climate Change Impacts on Freshwater Resources.” Overviews and Factsheets. October 18, 2022. <https://www.epa.gov/climateimpacts/climate-change-impacts-freshwater-resources>.
- _____. 2022c. “Closing America’s Wastewater Access Gap.” Overviews and Factsheets. August 1, 2022. <https://www.epa.gov/water-infrastructure/closing-americas-wastewater-access-gap>.
- _____. 2022d. “Closing America’s Wastewater Access Gap: Wastewater Challenges in Rural America.” Overviews and Factsheets. Water Infrastructure, Office of Water. August 1, 2022. <https://www.epa.gov/water-infrastructure/closing-americas-wastewater-access-gap>.
- _____. 2022e. “Community-Based Water Resiliency Guide.” Other Policies and Guidance EPA 817–B–22–007. Office of Water. https://web.archive.org/web/20250224101201/https://www.epa.gov/system/files/documents/2022-10/220914-CBWR_508c.pdf.
- _____. 2022f. “Lagoon Wastewater Treatment Action Plan: Supporting Small, Rural, and Tribal Communities.” EPA-832-B2-2002. Washington D.C.: Office of Wastewater Management, Office of Science and Technology, Office of Enforcement and Compliance Assurance. https://www.epa.gov/system/files/documents/2022-10/Lagoon%20Action_Plan_FINAL.pdf.
- _____. 2022g. “The Universe of Lagoons: An Analysis of State and Tribal Lagoon Wastewater Treatment Systems and Socioeconomic, Environmental Justice, and Compliance Patterns in Small, Rural Communities in the United States.” EPA-823-R-22-001. Washington D.C.: Office of Water. <https://www.epa.gov/system/files/documents/2022-06/universe-lagoons-report-2022.pdf#:~:text=Small%2C%20rural%20communities%20in%20the%20United%20States,for%20operation%20and%20maintenance%20of%20wastewater%20facilities.&text=It%20is%20imperative%20to%20address%20water%20quality,and%20public%20health%2C%20creating%20environmental%20justice%20concerns>.
- _____. 2023a. “Case Studies That Demonstrate the Benefits of Water Reuse.” Office of Water. October 17, 2023. <https://www.epa.gov/waterreuse/case-studies-demonstrate-benefits-water-reuse>.
- _____. 2023b. “Drinking Water Planning For Resilience: Pueblo of Laguna Utility Authority, New Laguna, New Mexico.” <https://www.epa.gov/crwu/adaptation-case-studies-water-utilities>.
- _____. 2023c. “Drinking Water System Infrastructure Resilience and Sustainability.” Overviews and Factsheets. March 17, 2023. <https://www.epa.gov/dwcapacity/drinking-water-system-infrastructure-resilience-and-sustainability>.

- _____. 2023d. “How the Drinking Water State Revolving Fund Works.” Drinking Water State Revolving Fund (DWSRF). 2023. <https://www.epa.gov/dwsrf/how-drinking-water-state-revolving-fund-works#tab-1>.
- _____. 2023e. “Increasing Climate Resilience and Mitigation with the Clean Water State Revolving Fund (CWSRF) and Water Infrastructure and Innovation Act (WIFIA) Program.” 832F23001. <https://www.epa.gov/system/files/documents/2023-03/climate-resilience-and-mitigation-with-cwsrf-and-wifia.pdf>.
- _____. 2023f. “Mutual Aid and Assistance for Drinking Water and Wastewater Utilities.” Overviews and Factsheets. Emergency Response for Drinking Water and Wastewater Utilities, Office of Water. 2023. <https://www.epa.gov/waterutilityresponse/mutual-aid-and-assistance-drinking-water-and-wastewater-utilities>.
- _____. 2023g. “Training and Technical Assistance (TA) Program for Rural, Small, and Tribal Wastewater Systems.” Overviews and Factsheets. Office of Water. April 26, 2023. <https://www.epa.gov/small-and-rural-wastewater-systems/training-and-technical-assistance-ta-program-rural-small-and>.
- _____. 2023h. “Wastewater Planning for Resilience: Beaufort-Jasper Water & Sewer Authority, Okatie, South Carolina.” Office of Water. <https://www.epa.gov/crwu/adaptation-case-studies-water-utilities>.
- _____. 2023i. “Water and Wastewater Planning for Resilience: Village of Hershey, Nebraska.” Office of Water. <https://www.epa.gov/crwu/adaptation-case-studies-water-utilities>.
- _____. 2024a. “About the Clean Water State Revolving Fund (CWSRF).” Clean Water State Revolving Fund. 2024. <https://www.epa.gov/cwsrf/about-clean-water-state-revolving-fund-cwsrf>.
- _____. 2024b. “Creating Resilient Water Utilities (CRWU).” Data and Tools. Office of Water. 2024. <https://www.epa.gov/crwu>.
- _____. 2024c. “Environmental Finance Centers: Environmental Finance Center Grant Program.” Overviews and Factsheets. Water Infrastructure and Resiliency Finance Center, Office of Water. 2024. <https://www.epa.gov/waterfinancecenter/efcn>.
- _____. 2024d. “EPA Fact Sheet: Risk and Resilience Assessment and Emergency Response Plan Requirements for Drinking Water Utilities.” <https://www.epa.gov/system/files/documents/2024-07/awia-sdwa1433-factsheet.pdf>.
- _____. 2024e. “Hazard Mitigation Assistance Programs Available to Water and Wastewater Utilities.” Overviews and Factsheets. Fed FUNDS for Water and Wastewater Utilities. 2024. <https://www.epa.gov/fedfunds/hazard-mitigation-assistance-programs-available-water-and-wastewater-utilities>.

- _____. 2024f. “Local Infrastructure Investment Stories.” Overviews and Factsheets. Water Infrastructure, Office of Water. 2024. <https://www.epa.gov/water-infrastructure/local-infrastructure-investment-stories>.
- _____. 2024g. “Resilience Training and Exercises for Drinking Water and Wastewater Utilities.” Overviews and Factsheets. Water Resilience, Office of Water. 2024. <https://www.epa.gov/waterresilience/resilience-training-and-exercises-drinking-water-and-wastewater-utilities>.
- _____. 2024h. “Safeguarding Against Natural Hazards and Extreme Weather Events: A Resource Guide for Onsite Wastewater Treatment Systems.” 830F24004. Office of Wastewater Management. <https://www.epa.gov/system/files/documents/2024-12/septic-tanks-and-natural-hazards-resource-guide.pdf>.
- _____. 2024i. “Sewer Overflow and Stormwater Reuse Municipal Grants Program.” Overviews and Factsheets. US EPA, Office of Water. July 23, 2024. <https://www.epa.gov/cwsrf/sewer-overflow-and-stormwater-reuse-municipal-grants-program>.
- _____. 2024j. “Source Water Protection Program.” Office of Water. Addressing Climate Change in the Water Sector. February 6, 2024. <https://www.epa.gov/climate-change-water-sector/source-water-protection-program>.
- _____. 2024k. “Technical Assistance for Rural, Small, and/or Tribal Lagoon Wastewater Treatment Systems.” <https://www.epa.gov/system/files/documents/2024-05/lagoon-wastewater-treatment-technical-assistance-fact-sheet.pdf>.
- _____. 2024l. “Water Affordability Needs Assessment: Report to Congress.” EPA 830-R-24-015. https://www.epa.gov/system/files/documents/2024-12/water-affordability-needs-assessment.pdf?utm_source=WNA+MasterList&utm_campaign=ba00d60c3c-EMAIL_CAMPAIGN_2023_08_30_09_14_COPY_01&utm_medium=email&utm_term=0_-de38b76327-325545355&mc_cid=ba00d60c3c&mc_eid=7fb4e8d12f.
- _____. 2024m. “Water Reuse Case Study: The Alaska Water and Sewer Challenge.” Overviews and Factsheets. United States. 2024. <https://www.epa.gov/waterreuse/water-reuse-case-study-alaska-water-and-sewer-challenge>.
- _____. n.d.-a. “Climate Resilience Evaluation and Awareness Tool.” Creating Resilient Water Utilities (CRWU), Office of Water. Accessed September 3, 2024. <https://www.epa.gov/crwu/climate-resilience-evaluation-and-awareness-tool>.
- _____. n.d.-b. “Community-Based Water Resiliency Guide.”
- _____. n.d.-c. “EJScreen: Environmental Justice Screening and Mapping Tool.” Accessed July 11, 2023. <https://screening-tools.com/epa-ejscreen>.
- _____. n.d.-d. “Grantee Research Project Results: Development of Innovative Monitoring and Analysis Strategies for Rural Enhanced Aquifer Recharge Structures.” Accessed April 21, 2025. https://cfpub.epa.gov/ncer_abstracts/index.cfm.

- _____. n.d.-e. “Resilient Strategies Guide for Water Utilities.” Creating Resilient Water Utilities (CRWU), Office of Water. Accessed April 22, 2025. <https://www.epa.gov/crwu/resilient-strategies-guide-water-utilities>.
- _____. n.d.-f. “Tabletop Exercise Tool for Drinking and Waste Water Utilities.” Accessed December 19, 2024. <https://ttx.epa.gov/index.html>.
- _____. n.d.-g. “WaterSense.” Office of Water. Accessed April 21, 2025. <https://www.epa.gov/watersense>.
- _____. Memorandum to EPA Regional Water Division Directors, Regions 1-10. 2022h. “Amendments to the Sewer Overflow and Stormwater Reuse Municipal Grants Program and Allocation of Federal Fiscal Year 2022 Funding,” November 18, 2022. <https://www.epa.gov/system/files/documents/2022-11/OSG-BIL-amendments-and-FY22-allotment.pdf>.
- US Environmental Protection Agency, and US Department of Agriculture. 2016. “Rural and Small Systems Guidebook to Effective Utility Management.” https://www.epa.gov/sites/default/files/2016-06/documents/rural_and_small_systems_guidebook_-_may_2016_508.pdf.
- US Geological Survey, and Water Resources Mission Area. 2019. “Domestic (Private) Supply Wells.” 2019. <https://www.usgs.gov/mission-areas/water-resources/science/domestic-private-supply-wells>.
- US Geological Survey, Water Science School. 2018. “Irrigation Methods: Furrow or Flood Irrigation.” US Geological Survey. June 13, 2018. <https://www.usgs.gov/special-topics/water-science-school/science/irrigation-methods-furrow-or-flood-irrigation>.
- _____. 2024. “Climate Literacy: Essential Principles for Understanding and Addressing Climate Change.” Washington D.C., USA. <https://web.archive.org/web/20250203013442/https://downloads.globalchange.gov/Literacy/Climate-Literacy-Guide-2024.pdf>.
- _____. n.d. “Crowdsourcing Climate: Citizen Science and the National Climate Assessment.” Accessed April 22, 2025. <https://web.archive.org/web/20250629024811/https://globalchange.gov/highlights/crowdsourcing-climate-citizen-science-and-national-climate-assessment>.
- US Government Accountability Office. 2013. “Flood Insurance – Participation of Indian Tribes in Federal and Private Programs.” GAO-13-226. Washington, D.C. <https://www.gao.gov/assets/gao-13-226.pdf>.
- _____. 2016. “Water Infrastructure: Information on Selected Midsize and Large Cities with Declining Populations.” GAO-16-785. Washington, D.C. <https://www.gao.gov/assets/gao-16-785.pdf>.

- _____. 2022. “Small Business Administration: Targeted Outreach about Disaster Assistance Could Benefit Rural Communities.” Q&A Report to Congressional Committees GAO-24-106755. <https://www.gao.gov/products/gao-24-106755>.
- US National Park Service. n.d. “Alabama Black Belt National Heritage Area.” Accessed February 18, 2025. <https://www.nps.gov/places/alabama-black-belt-national-heritage-area.htm>.
- US Water Alliance. 2017. “An Equitable Water Future: A National Briefing Paper.” https://uswateralliance.org/wp-content/uploads/2023/09/uswa_waterequity_FINAL.pdf.
- _____. 2022. “Advancing Racial Equity Across the Water Sector: A Toolkit for Utilities.” <https://uswateralliance.org/resources/racial-equity-toolkit/>.
- _____. 2023. “Advancing Water Equity in Small and Rural Communities: The Role of Digital Solutions.” Transforming Water Management Post COVID-19. <https://uswateralliance.org/wp-content/uploads/2023/09/Advancing-Water-Equity-in-Small-and-Rural-Communities%E2%80%94The-Role-of-Digital-Solutions.pdf>.
- USDA Climate Hubs. n.d.-a. “Climate Change Adaptation Workshop with the Dixie National Forest.” Accessed April 18, 2025. <https://www.climatehubs.usda.gov/hubs/southwest/topic/climate-change-adaptation-workshop-dixie-national-forest>.
- _____. n.d.-b. “Climate Literacy & Training.” Accessed April 18, 2025. <https://www.climatehubs.usda.gov/priorities/climate-literacy-training>.
- Václavík, Tomáš, Fanny Langerwisch, Marc Cotter, Johanna Fick, Inga Häuser, Stefan Hotes, Johannes Kamp, Josef Settele, Joachim H. Spangenberg, and Ralf Seppelt. 2016. “Investigating Potential Transferability of Place-Based Research in Land System Science.” *Environmental Research Letters* 11 (9): 095002. <https://doi.org/10.1088/1748-9326/11/9/095002>.
- Van Oijstaeijen, Wito, Steven Van Passel, and Jan Cools. 2020. “Urban Green Infrastructure: A Review on Valuation Toolkits from an Urban Planning Perspective.” *Journal of Environmental Management* 267 (August):110603. <https://doi.org/10.1016/j.jenvman.2020.110603>.
- Vandermeulen, Valerie, Ann Verspecht, Bert Vermeire, Guido Van Huylenbroeck, and Xavier Gellynck. 2011. “The Use of Economic Valuation to Create Public Support for Green Infrastructure Investments in Urban Areas.” *Landscape and Urban Planning* 103 (2): 198–206. <https://doi.org/10.1016/j.landurbplan.2011.07.010>.
- Vedachalam, Sridhar, Timothy Male, and Lynn Broadus. 2020. “H2Equity: Rebuilding a Fair System of Water Services for America.” Washington, D.C.: Environmental Policy Innovation Center. <https://www.policyinnovation.org/publications/h2equity>.
- Verduzco, Erik, Jeff Amy, and John Seewer. 2024. “Southerners Stay in Touch the Old-Fashioned Way after Helene Cuts Roads, Power, Phones.” News Release. AP News. October

- 2, 2024. <https://apnews.com/article/helene-asheville-north-carolina-3f812f70c4d2649e2198362e9ae42b06>.
- Vermont Department of Health. n.d. “After a Flood: Private Drinking Water Guidance.” Drinking Water. Accessed March 31, 2025. <https://www.healthvermont.gov/environment/drinking-water/after-flood-private-drinking-water-guidance>.
- Vigerstol, K., N Karres, S Kang, M. Lilly, and M. Massey-Bierman. 2023a. “Accelerating Adaptation: The Promise and Limitations of Nature-Based Solutions in the Race to Adapt to Increasing Floods and Droughts.” Arlington, VA, USA: The Nature Conservancy. <https://www.nature.org/en-us/what-we-do/our-insights/perspectives/accelerating-adaptation-nature-based-solutions/>.
- Virginia Interfaith Power & Light. n.d. “Are You #ThirstyForWaterJustice?” Accessed April 18, 2025. <https://vaip.org/water/>.
- Vorhees, Lauren, Jane Harrison, Michael O’Driscoll, Charles Humphrey, and Jared Bowden. 2022. “Climate Change and Onsite Wastewater Treatment Systems in the Coastal Carolinas: Perspectives from Wastewater Managers,” November. <https://doi.org/10.1175/WCAS-D-21-0192.1>.
- Voth-Gaeddert, Lee E., Douglas Momberg, Kela Brathwaite, Andrew Schranck, Stephen Libbey, and Mandy Lemley. 2022. “Evaluating the Costs and Components of a Territory-Wide Household Water Storage and Treatment Program in the US Virgin Islands.” *Water Policy* 24 (10): 1692–1703. <https://doi.org/10.2166/wp.2022.127>.
- Wake County North Carolina. n.d. “Well & Septic Pilot Assistance Fund.” Wake County Government. Accessed February 14, 2025. <https://www.wake.gov/departments-government/onsite-water-protection/programs-help-your-septic-repairs-well-repairs-water-treatment-well-testing/well-septic-pilot-assistance-fund>.
- Walls, Margaret A., Emma DeAngeli, and Yanjun (Penny) Liao. 2023. “As Sea Levels Rise, So Does Wastewater.” Resources for the Future. 2023. <https://www.resources.org/archives/as-sea-levels-rise-so-does-wastewater/>.
- Walton, Brett. 2018. “Straight Pipes Foul Kentucky’s Long Quest to Clean Its Soiled Waters.” *Circle of Blue* (blog). February 28, 2018. <https://www.circleofblue.org/2018/world/straight-pipes-foul-kentuckys-long-quest-clean-soiled-waters/>.
- _____. 2019. “Severe Drinking Water Contamination Surfaces After Brutal Camp Fire.” Circle of Blue. March 7, 2019. <http://www.circleofblue.org/2019/supply/water-quality/severe-drinking-water-contamination-surfaces-after-brutal-camp-fire/>.
- Wandersee, Michael, Dara Zimmerman, Kelly Kachurak, Leo Angelo Gumapas, Kayla Devault Wendt, and Kurt Kesteloot. 2023. “Wildland Fires Could Be Putting Your Drinking Water at Risk.” US National Park Service). 2023. <https://www.nps.gov/articles/000/wildland-fires-could-be-putting-your-drinking-water-at-risk.htm>.

- Washington State Department of Commerce. 2022. “Environmental Justice Community Engagement Plan.” <https://www.commerce.wa.gov/wp-content/uploads/2022/06/Commerce-EJ-Community-Engagement-Plan.pdf>.
- _____. 2024. “Weatherization.” Washington State Department of Commerce. April 10, 2024. <https://www.commerce.wa.gov/weatherization/>.
- Washington State Department of Ecology. 2024. “Clean Water State Revolving Fund: Emergency Funding Program Guidelines.” Publication 24-10-006. Olympia, Washington: Washington State Department of Ecology. <https://apps.ecology.wa.gov/publications/documents/2410006.pdf>.
- _____. n.d. “Yakima River Basin Integrated Plan.” Accessed December 23, 2024. <https://ecology.wa.gov/ecologys-work-near-you/river-basins-groundwater/yakima-river-basin-projects/yakima-integrated-plan>.
- Washington State Legislature. 2023. *Engrossed Substitute House Bill 1329*. <https://app.leg.wa.gov/billsummary?BillNumber=1329&Initiative=false&Year=2023#:~:text=HB%201329%20Washington%20State%20Legislature&text=Preventing%20utility%20shutoffs%20for%20nonpayment%20during%20extreme%20heat.&text=Referred%20to%20Rules%20%20Review.&text=Placed%20on%20second%20reading%20by%20Rules%20Committee>.
- Wasley, E., T.A. Dahl, C.F. Simpson, L.W. Fischer, J.F. Helgeson, M.A. Kenney, A. Parris, A.R. Siders, E. Tate, and N. Ulibarri, 2023: Ch. 31. Adaptation. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. <https://web.archive.org/web/20250630050610/https://nca2023.globalchange.gov/chapter/31/>.
- Water Hub. 2024. “Speaking to the Heart: Storytelling for Social Change.” <https://waterhub.org/wp-content/uploads/2024/10/storytelling-for-change-water-hub-sept-2024.pdf>.
- Water Infrastructure Finance Authority of Arizona. n.d. “Water Supply Development Fund.” Accessed April 18, 2025. <https://www.azwifa.gov/programs/funding-type/wsdf>.
- Water Resources Alliance. 2024. “Three Water Management Challenges for Small Water & Wastewater Treatment Plants.” Professional Water and Wastewater Operations. 2024. <https://alliancewater.com/3-challenges-for-small-water-treatment-plants/>.
- Water Utility Climate Alliance. 2024. “CMIP6 Frequently Asked Questions: A Resource for Water Managers.” 2024. <https://www.wucaonline.org/adaptation-in-practice/cmip6-faqs/index.html>.
- WaterAid. 2021. “Programme Guidance for Climate Resilient WASH.” <https://washmatters.wateraid.org/sites/g/files/jkxoof256/files/programme-guidance-for-climate-resilient-water-sanitation-and-hygiene.pdf>.

- WaterAid, Australian Aid, and Water for Women. 2021. “Integrating Climate Resilience with WASH System Strengthening.” WaterAid.
<https://washmatters.wateraid.org/sites/g/files/jkxoof256/files/integrating-climate-resilience-with-wash-system-strengthening.pdf>.
- WaterNow Alliance. 2024. “Wake County Project Accelerator: Phase 5 Memo.”
https://waternow.org/wp-content/uploads/2024/04/Wake-County-Community-Engagement-and-Outreach-Toolkit_E.pdf.
- _____. n.d.-a. “Eagle River Coalition & Eagle County Conservation District, CO: Beyond Lawn Water Efficient Landscape Conversion Program.” WaterNow Alliance. Accessed February 25, 2025. <https://waternow.org/project/eagle-river-watershed-council-eagle-county-conservation-district-co/>.
- _____. n.d.-b. “Emerging Leader Awards.” WaterNow Alliance. Accessed April 18, 2025. <https://waternow.org/emerging-leader-awards/>.
- _____. n.d.-c. “Wake County, NC Equitable Outreach Strategy for Well & Septic Financial Assistance Pilot Program.” WaterNow Alliance. Accessed February 7, 2025. <https://waternow.org/project/wake-county-nc/>.
- West Virginia Rivers. 2023. “Harpers Ferry Designated as a Source Water Community.”
<https://www.harpersferrywv.us/water/misc/wvrivers-hf-announcement-20231005.pdf>.
- West Virginia University Institute of Sustainability and Energy. n.d. “Appalachian Community Technical Assistance and Training | Water WORCs in Appalachia.” Accessed March 17, 2025. <https://actat.wvu.edu/water-worcs>.
- Whelton, Andrew J., Chad Seidel, Brad P. Wham, Erica C. Fischer, Kristofer Isaacson, Caroline Jankowski, Nathan MacArthur, Elizabeth McKenna, and Christian Ley. 2023. “The Marshall Fire: Scientific and Policy Needs for Water System Disaster Response.” *AWWA Water Science* 5 (1). <https://doi.org/10.1002/aws2.1318>.
- White, D.D., E.H. Elias, K.A. Thomas, C.E. Bradatan, M.W. Brunson, A.M. Chischilly, C.A.F. Enquist, L.R. Fisher, H.E. Froehlich, E.A. Koebele, M. Méndez, S.M. Ostoja, C. Steele, and J.K. Vanos, 2023: Ch. 28. Southwest. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.
<https://web.archive.org/web/20250630050610/https://nca2023.globalchange.gov/chapter/28/>.
- Whyte, K., R. Novak, M.B. Laramie, N.G. Bruscato, D.M. David-Chavez, M.J. Dockry, M.K. Johnson, C.E. Jones Jr., and K. Leonard, 2023: Ch. 16. Tribes and Indigenous Peoples. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA.

- <https://web.archive.org/web/20250630050645/https://nca2023.globalchange.gov/chapter/16/>.
- Whyte, Kyle Powys. 2018. "Indigenous Science (Fiction) for the Anthropocene: Ancestral Dystopias and Fantasies of Climate Change Crises." *Environment and Planning E: Nature and Space* 1 (1–2): 224–42. <https://doi.org/10.1177/2514848618777621>.
- Wild Salmon Center, dir. 2022. *Natural Infrastructure: Quillayute River*. <https://vimeo.com/779362305>.
- Wild, Tom C., John Henneberry, and Lewis Gill. 2017. "Comprehending the Multiple 'Values' of Green Infrastructure – Valuing Nature-Based Solutions for Urban Water Management from Multiple Perspectives." *Environmental Research* 158 (October):179–87. <https://doi.org/10.1016/j.envres.2017.05.043>.
- Wilker, Jost, and Karsten Rusche. 2014. "Economic Valuation as a Tool to Support Decision-Making in Strategic Green Infrastructure Planning." *Local Environment* 19 (6): 702–13. <https://doi.org/10.1080/13549839.2013.855181>.
- Wilker, Jost, Karsten Rusche, and Christine Ryma-Fitschen. 2016. "Improving Participation in Green Infrastructure Planning." *Planning Practice & Research* 31 (3): 229–49. <https://doi.org/10.1080/02697459.2016.1158065>.
- Will, Rachel. 2019. "The Greening of Atlanta: Socio-Ecological Outcomes on the Atlanta Beltline." PhD, Athens, Georgia, USA: University of Georgia. <https://esploro.libs.uga.edu/esploro/outputs/doctoral/The-greening-of-Atlanta-socio-ecological-outcomes/9949334815702959>.
- Willems, Jannes J., Astrid Molenveld, William Voorberg, and Geert Brinkman. 2020. "Diverging Ambitions and Instruments for Citizen Participation across Different Stages in Green Infrastructure Projects." *Urban Planning* 5 (1): 22–32. <https://doi.org/10.17645/up.v5i1.2613>.
- Wlostowski, Adam N., Keith S. Jennings, Rachel E. Bash, Jesse Burkhardt, Cameron W. Wobus, and Graeme Aggett. 2021. "Dry Landscapes and Parched Economies: A Review of How Drought Impacts Nonagricultural Socioeconomic Sectors in the US Intermountain West." *WIREs Water* 9 (1). <https://doi.org/10.1002/wat2.1571>.
- Wolch, Jennifer R., Jason Byrne, and Joshua P. Newell. 2014. "Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'Just Green Enough.'" *Landscape and Urban Planning* 125 (May):234–44. <https://doi.org/10.1016/j.landurbplan.2014.01.017>.
- World Meteorological Organization. 2025. "State of the Global Climate 2024." WMO-No. 1368. <https://wmo.int/publication-series/state-of-global-climate-2024>.
- Young, Lewis, Katie Fry Hester, and Jim Rosapepe. 2023. *Maryland Private Well Safety Act of 2023*. <https://mgaleg.maryland.gov/mgawebsite/Legislation/Details/SB0483?ys=2023RS>.

- Yukon River Inter-Tribal Watershed Council. 2022. “Climate Adaptation Strategies.” 2022. <https://www.yritwc.org/climate-adaptation-strategies>.
- Zach, Elizabeth. 2016. “Middletown Slowly Rebuilding after Massive Wildfire.” RCAC (blog). June 23, 2016. <https://www.rcac.org/rural-stories/middletown-slowly-rebuilding-massive-wildfire/>.
- Zhang, Xue, Mildred E. Warner, and Mary Grant. 2022. “Water Shutoff Moratoria Lowered COVID-19 Infection and Death Across U.S. States.” *American Journal of Preventive Medicine* 62 (2): 149–56. <https://doi.org/10.1016/j.amepre.2021.07.006>.



pacinst.org