Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States

WATER, SANITATION, AND CLIMATE CHANGE IN THE UNITED STATES SERIES, PART 1

JANUARY 2024

JANUARY 2024

Climate Change Impacts to Water and Sanitation for Frontline Communities in the United States

WATER, SANITATION, AND CLIMATE CHANGE IN THE UNITED STATES SERIES, PART 1

EDITORS
Shannon McNeeley, Pacific Institute, Senior Researcher; Water and Climate Equity Lead
Morgan Shimabuku, Pacific Institute, Senior Researcher

CONTRIBUTING AUTHORS
Morgan Shimabuku, Pacific Institute
Shannon McNeeley, Pacific Institute
Nora Nelson, DigDeep
Antonia Sohns, independent contractor

SUGGESTED CITATION
Pacific Institute and DigDeep, 2024. Climate Change Impacts to Water and Sanitation in Frontline Communities in the United States, Water, Sanitation, and Climate Change in the US Series, Part 1, Pacific Institute, Oakland, CA https://pacinst.org/water-sanitation-climate-change-US-part-1/

PACIFIC INSTITUTE DIGDEEP CWSC THE CENTER FOR WATER SECURITY AND COOPERATION

This report is an update of the previously released version *Climate Change Impacts to Water and Sanitation in Frontline Communities in the United States (working document)* we made available in November of 2023. We have made important updates with the subsequent release of the Fifth National Climate Assessment as well as some other corrections.

Cover photo provided by DigDeep

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 DIG DEEP

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

ABOUT CENTER FOR WATER SECURITY AND COOPERATION

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

ABOUT THE AUTHORS

Morgan Shimabuku

Morgan Shimabuku is a Senior Researcher at 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 B.A. in Environmental Studies and Geology from Whitman College and a master's degree from the Department of Geography at the University of Colorado Boulder, where she studied climate change, hydrochemcial cycling, and snow hydrology at the Institute of Arctic and Alpine Research.

Shannon McNeeley

Shannon McNeeley is a Senior Researcher at Pacific Institute and the Water and Climate Equity Lead. Her work focuses on water and climate equity and justice for frontline communities. This engages an interdisciplinary and cross-cultural co-production approach, incorporating the social and natural sciences along with different ways of knowing to understand human-environment relationships and how people are impacted by and respond to environmental change. Her research has focused on climate change science and policy, water resources and drought preparedness, and climate planning and action, all with a strong focus on supporting those who are overburdened and under resourced 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. Shannon holds an M.A. in International Environmental Policy from the Middlebury Institute of International Studies at Monterey and a Ph.D. in Environmental Change and Sustainability Science, which integrated anthropology, ecology, and climatology, from the University of Alaska Fairbanks (UAF).

Nora Nelson

Nora Nelson is an international climate change, water, and sustainable landscapes expert with experience in 40 countries. At DigDeep, she led the research efforts behind the reports *Closing the Water Access Gap in the United States* and *Draining: The Economic Impact of America's Hidden Water Crisis.* Nora has previously worked for the International Water Management Institute, the United Nations Convention to Combat Desertification, Landesa, and a variety of other international research organizations, donors, and development partners. She provides regular technical advisory and consulting services to USAID, including serving as the team leader for the global analysis of climate risk management at the Agency Nora holds a Bachelor's degree from Knox College in environmental science and biology, a Master's degree from the American University School of International Service in water resource management, and a Master's degree from the United Nations Universidad para la Paz in natural resources and sustainable development.

Antonia Sohns

Antonia Sohns is a postdoctoral researcher at McGill University where her research explores wellbeing and water justice with Indigenous youth in Alaska and the Peruvian Amazon through artistic practice. Antonia has worked as an environmental consultant in the U.S. and internationally, where her projects focused on water security and climate change, including citizen science to monitor climate impacts, watershed management plans, and remote sensing of dams and reservoirs. Antonia has a PhD in Geography from McGill University; an MSc in Water Science, Policy and Management from the University of Oxford; and a BSc in Earth Systems (Oceans Track) from Stanford University.

ACKNOWLEDGEMENTS

Alexandra Campbell-Ferrari, Kim Lemme, George McGraw, Heather Cooley, Peter Gleick, Jess Dery, Jackie Rigley, and DigDeep staff. Each provided essential guidance, input, feedback, review, and/or support for this report. This work was generously supported by the BHP Foundation.

DEDICATION

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

Water is life.

Table of Contents

Figures, Tables, and Boxes

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, healthcare, food, and other utilities (Teodoro 2019; Feinstein 2018).

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

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

Community water system: A public water system that supplies water to the same population year-round (US Environmental Protection Agency 2015d).

Disadvantaged communities (DACs): The White House Climate and Economic Justice Screening tool identifies census tracts that are overburdened and underserved. This also includes Federally Recognized Tribes, including Alaska Native Villages. Under the Safe Drinking Water Act, 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 under resourced who face disproportionate, "first and worst" impacts of climate change on their water and sanitation systems or access.

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 United States include the 574 federally recognized Tribes (as of 2023), Native Hawaiians, Pacific and Caribbean islanders, state-recognized Tribes, and unrecognized Tribes and peoples. More specific terms will be used where the particular government, legal, cultural, or diplomatic situation is being 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.

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, non-transient non-community water systems, and transient non-community water systems (US Environmental Protection Agency 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 conveyance, storage, treatment, and disposal of human waste. This includes toilets, pipes that remove wastewater from the home, and treatment measures (Roller et al. 2019).

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

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

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

Wastewater services (or systems): The provision of centralized sewer systems and treatment plants, individual septic systems, or other forms of decentralized or on-site 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 insecurity: inadequate or inequitable access to clean, safe, and affordable water for drinking, cooking, sanitation, and hygiene. Water insecurity results from a combination of social and physical conditions, including climate change (Schimpf and Cude 2020).

Photo provided by DigDeep

1. Introduction: Intersection of Water, Sanitation, and Climate Change

Climate change is among the most urgent, wide-ranging crises we face. It poses significant challenges and is already resulting in severe impacts to drinking water and sanitation access. This is true for both those currently living without access and for communities where forces like drought, flooding, sea level rise, wildfires, and intensifying storms threaten backsliding by degrading or stripping basic water and sanitation services from the people. Access to sufficient, safe, acceptable, physically accessible, and affordable water and sanitation is essential for human health and wellbeing, as well as economic prosperity—and climate change will inevitably make ensuring all have access more challenging. Without water and sanitation access, people do not have water to drink, cannot clean, shower, or wash their hands, and cannot safely dispose of human waste. They may have to travel long distances to purchase and haul water back to their homes. Without access to water, they also have less ability to cool their homes, protect themselves from wildfires, and work or go to school. An economic assessment by DigDeep found that for every household in the United States without access to water and sanitation, the domestic economy loses $15,800 annually in extra health care costs, time and money spent on bottled water, lost educational or work opportunities, and premature death (DigDeep 2022).

Despite the central importance of water and sanitation access, there are major gaps across the United States. While no comprehensive assessment exists, several recent studies offer glimpses of the scope and scale of the water and sanitation access problem. Roller et al. (2019) estimated that more than 2 million people in the United States live without access to running water and basic indoor plumbing, and many more lack sanitation. Deitz and Meehan (2019) found that African-American, Latino and Hispanic, and Native American households are more likely than white households to lack complete plumbing (a term used by the US Census Bureau to track the presence of piped hot and cold water, a flush toilet, and a bathtub or shower).[1] During a drought from 2012–2016 in the Central Valley of California, the Pacific Institute found that the state documented nearly 4,000 reports of water shortages from households with private wells or other small non-public water systems (those with fewer than 15 connections or serving fewer than 25 people at least 60 days a year) (Feinstein et al. 2017). These are just a few of the studies that have helped bring to light the water access gap in the United States.

---

[1] Roller et al. (2019) and Dietz and Meehan (2019) used data from the American Community Survey by the US Census Bureau for their studies; it is the only national survey of plumbing facilities in US households and no longer asks if a home has a flush toilet.

Poor water quality also poses a risk to water access for households and communities across the United States. An estimated 23 million households rely on private water wells (Murray et al. 2021), and there is little data on the quality of this water. Allaire et al. (2018) found that violations of health-based water-quality standards in community water systems were widespread, with an estimated 9–45 million people potentially affected annually in the continental United States alone. The authors found that violations were more common in rural areas, especially among low-income communities. Further, even if the water is safe when delivered to a household, it can become contaminated with, for example, lead and copper from corroding service lines and plumbing fixtures.

Climate change is creating additional challenges for addressing the water access gap. The Fourth and Fifth US National Climate Assessments found that climate change is already altering water quantity, quality, and demand, as well as the threat of extreme events (Lall et al. 2018; Payton et al. 2023).[2] It also found that problems with critical water infrastructure, which is reaching the end of its design life in many parts of the United States, compound these climate risks.

> The impacts of climate change on water and sanitation are already evident and are expected to intensify as atmospheric greenhouse gas concentrations continue to rise.

The impacts of climate change on water and sanitation are already evident and are expected to intensify as atmospheric greenhouse gas concentrations continue to rise. As of the writing of this report in the fall of 2023, the United States had experienced record-breaking heat and climate change impacts. National Aeronautics and Space Administration (NASA) scientists reported July 2023 to be the hottest month ever recorded on Earth since 1880 (NASA 2023; News Editor 2023). This was followed by four more record-breaking months, which were the hottest August, September, October, and November months on Earth on record (NOAA 2023c; 2023d; 2023e; 2023f). In the United States, heat records were broken not only for all-time highs, but also for number of consecutive days that certain heat thresholds were surpassed (Thompson 2023). There were 15 billion-dollar disasters from January to July, the highest number ever recorded in this seven-month timeframe since the National Ocean and Atmospheric Administration (NOAA) began tracking these events in 1980 (NOAA 2023b). NOAA reported that these included 13 severe weather events, one winter storm, and one flooding event. Without immediate reductions in greenhouse gas emissions these severe consequences of climate change on water and sanitation will continue to worsen, and low-income communities and communities of color will suffer the worst.

The need for global action on climate change was identified over a half century ago, as early as the 1972 United Nations Conference on the Human Environment (also known as the Stockholm Convention) (United Nations 1972). This led to the establishment of the first international treaty to tackle climate change in 1992, the UN Framework Convention on Climate Change, and subsequent treaties to implement measures to reduce greenhouse gases such as the 2015 Paris Agreement. The global scientific community agrees that human activities, namely the burning of fossil fuels,

---

[2] Water quantity refers to the amount of water available in a specific location at a given time, and water quality refers to the chemical, physical, and biological characteristics of water, including its clarity, odor, taste, and the presence of contaminants.

has caused climate change and that we are already seeing the effects (Wuebbles et al. 2017; Intergovernmental Panel on Climate Change 2021; Marvel et al. 2023). The United Nations defines climate change as “a change of climate which 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,” typically decades or longer (United Nations Framework Convention on Climate Change 1994).[3] Trends in global phenomena that indicate we are already experiencing a rapidly changing global climate include an increase in global average temperature, sea level rise, warming ocean temperatures, melting of glacial and Arctic ice, aridification and the expansion of deserts, deeper permafrost thaw, and more (Intergovernmental Panel on Climate Change 2021). The impacts of climate change are also becoming clearer through an increase in the frequency and intensity of extreme heat and precipitation events, but there are regional differences in the observed trends and in other extreme events like floods and droughts (Wuebbles et al. 2017; Herring et al. 2022; Marvel et al. 2023).

There is a growing body of literature on both the impacts of climate change on water *and* the gap in water and sanitation access. However, there are few studies that address the intersection of these issues. This report seeks to help fill that gap by beginning to establish the scientific knowledge base as a starting point. For this work, the Pacific Institute partnered with DigDeep and Center for Water Security and Cooperation to review the literature on the effects of climate change on water and sanitation systems and water resources in the United States, especially for frontline communities. In this report, we define frontline communities as those that are overburdened and under resourced who face the disproportionate, “first and worst” impacts of climate change on their water and sanitation systems or access. With this synthesis of knowledge, experiences, and information, we hope to provide a foundation for understanding—and ultimately reducing—the impacts of climate change on these communities. Importantly, climate impacts on water and sanitation systems and water resources co-occur with other challenges facing the water sector and frontline communities. Consequently, closing the water access gap while increasing the resilience of frontline communities to the impacts of climate change will require innovative approaches that also address contributing barriers, such as institutional constraints, lack of integrated water resource management, and structural and systemic racism.

This report is the first in what will be a series on the myriad issues at the intersection of water and climate equity called ***Water, Sanitation, and Climate Change in the United States***. Forthcoming reports will focus on the laws and policies that govern the delivery of water and sanitation in the face of climate change, barriers to equitable, climate-resilient water and sanitation, and documented strategies and approaches to overcome these barriers. Our hope is that this series will provide a foundation for the US water, sanitation, and hygiene (WASH) sector to incorporate and consider climate change in its efforts to close the water access gap.

---

[3] The Intergovernmental Panel on Climate Change defines climate change as “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.” They note the difference from the UN Framework Convention on Climate Change definition is a “distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.”

2. Vulnerability to Climate Change and Lack of Water and Sanitation Access

In *Climate Change and Social Vulnerability in the United States,* the US Environmental Protection Agency (EPA) identified and defined four socially vulnerable groups: 1) low income— individuals living in households with an income at or below 200% of the poverty level; 2) minority—individuals identifying as Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander, and/or Hispanic or Latino; 3) those without a high school diploma—individuals age 25 years or older with a maximum educational attainment of less than a high school diploma or equivalent; and 4) those who are 65 and older (US EPA 2021b). Additionally, people without housing are extremely vulnerable to natural hazards while also lacking access to water and sanitation (Ramin and Svoboda 2009). These vulnerable groups are often disproportionately impacted by environmental events, such as floods and hurricanes, or degraded environmental conditions, such as poor water quality.

Not all these groups are affected in the same way by climate disasters. The EPA estimated the risks for each socially vulnerable group relative to a “reference population,” or to all individuals outside of each group, under multiple warming scenarios and sea level rise of 50 cm (20 in) (US EPA 2021b). When looking at groups that include multiple races, they found under a 2°C (3.6°F) warming scenario that low-income groups and individuals are 16% more likely to live in places where the highest percentage of land is projected to be inundated by sea level rise and are 25% more likely to live in areas with the highest projected reductions in labor hours due to extreme temperatures. They found adults with no high-school diploma are at higher risk for coastal flooding and property inundation, as well as from air quality and extreme temperature impacts on labor. Those 65 and older are generally not more at risk than their younger counterparts but are at slightly elevated risks from extreme temperatures and from property damage from inland flooding.

When considering race, the EPA found Black and African American individuals are at higher risks from damages and losses due to both coastal and inland flooding, but the largest risks for this group are from extreme temperatures and air quality (US EPA 2021b). This is because as the climate changes, it alters the chemical and physical processes that create, remove, and transport air pollution; and research has shown that even though the average concentration of air pollutants has fallen over time, it has remained disproportionately distributed across the population (Tessum et al.

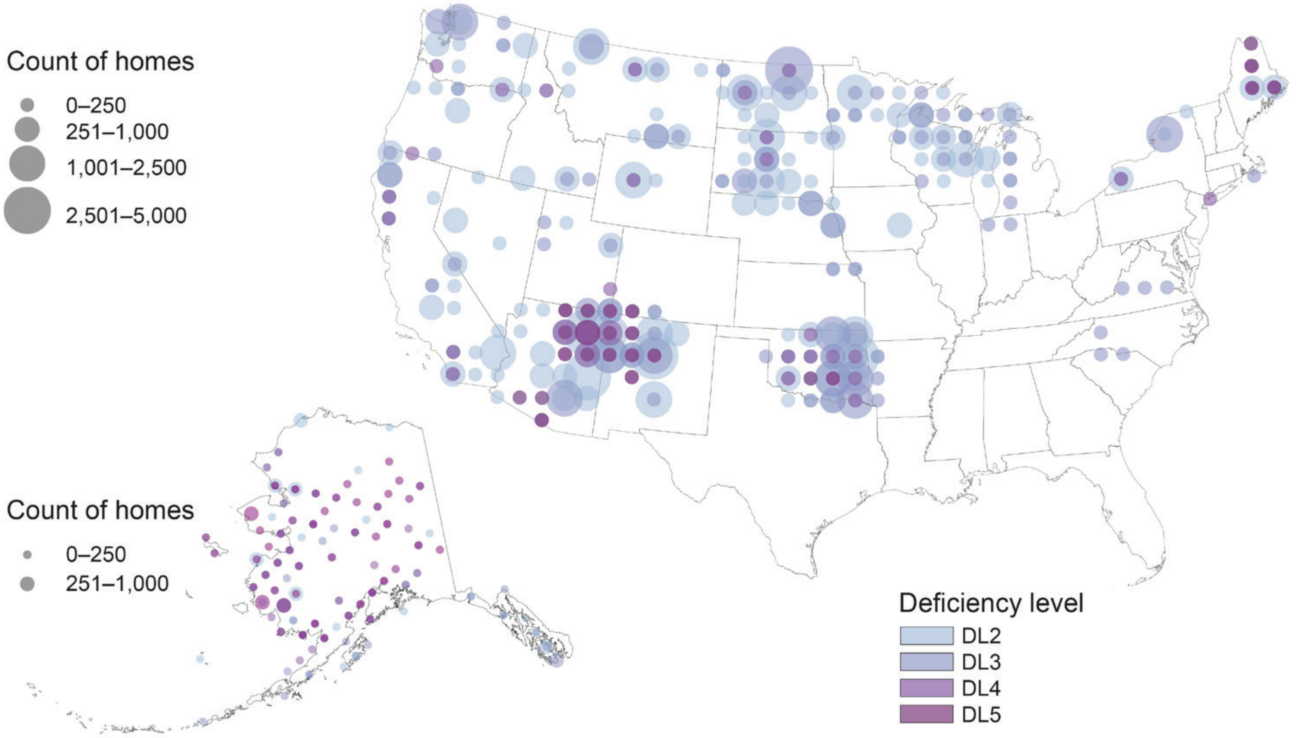
2021; Colmer et al. 2020). The EPA also found that Black Americans are 40–59% more likely to live in areas with the highest projected increases in deaths from extreme temperatures. They also found Tribal and Indigenous people (officially referred to as American Indian and Alaska Native by the federal government) are more likely than other groups to live in areas where they are at risk of land lost to inundation and have the highest rates of labor hour losses for weather-exposed workers due to extreme temperatures.

The EPA also showed that climate change disproportionately affects Hispanic and Latino individuals, who have high labor force participation in weather-exposed industries like construction and agriculture (US EPA 2021b). Under a 2°C (3.6°F) warming scenario, Hispanic and Latino individuals are 43% more likely to live in areas with the highest projected loss of labor hours due to extreme temperatures. Under the same scenario, Hispanic and Latino individuals are also 50% more likely to live in areas with the greatest estimated negative impacts on traffic, further harming economic productivity and increasing opportunity costs for individuals. All these factors compound stressors and strain resources for frontline communities, further affecting their ability to manage and adapt to climate change and its impacts on water and sanitation systems.

> Many frontline communities are also found in “hotspots of plumbing poverty” where households that suffer from limited-to-no access to water and sanitation services are clustered.

Many frontline communities are also found in “hotspots of plumbing poverty” where households that suffer from limited-to-no access to water and sanitation services are clustered (Deitz and Meehan 2019). These clusters of inadequate water and sanitation stem from disputes over rights and jurisdiction, inconsistent regulation, lack of investment in infrastructure, environmental racism, and water scarcity due to climate change and over-extraction for other human uses (Deitz and Meehan 2019; Conroy-Ben and Richard 2018; Cozzetto et al. 2013). For example, numerous Indigenous communities in the contiguous United States and Alaska lack adequate water and sanitation access (Figure 1) (Payton et al. 2023); Indian Health Service reported in Fiscal Year 2019 that more than 400,000 American Indian and Alaska Native homes had deficient sanitation (Indian Health Service 2020).

FIGURE 1. **American Indian and Alaska Native Homes Requiring Water and Sewer System Improvements**

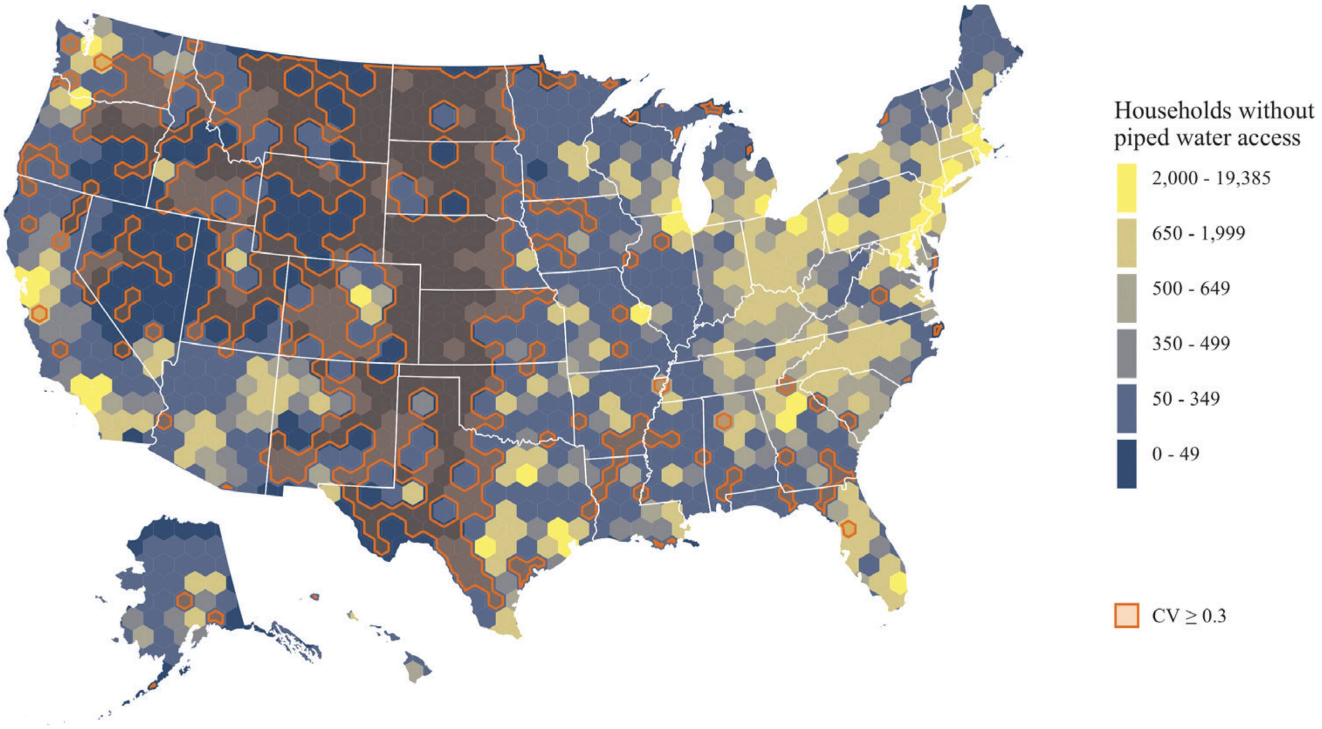


Note: The map reports number of American Indian and Alaska Native households with a plumbing deficiency level (DL) ranging from level 2 (capital improvements are necessary to meet domestic sanitation needs) to level 5 (lacks a safe water supply and a sewage disposal system).

Source: Payton et al. 2023

While national data on household access to drinking water and sanitation are incomplete, work by DigDeep (Roller et al. 2019) and several other researchers (Mueller and Gasteyer 2021; Meehan et al. 2020; Deitz and Meehan 2019) have identified hotspots with either a high number or large proportion of unplumbed households, or households with water that is unsafe to drink. Meehan et al. (2020) identified that the majority of unplumbed households in the United States were in cities, and that these households were more likely to be renters, households of color, and people living in areas of growing income inequality (Figure 2). Regional hotspots identified include the California Central Valley, the Navajo Nation, *colonias* along the border with Mexico, the Deep South, Appalachia, and Puerto Rico (Roller et al. 2019; Mueller and Gasteyer 2021).

FIGURE 2. **Households Without Piped Water Access in the United States, 2013 to 2017**



Note: This hex map depicts the spatial distribution of households without piped water access, with lighter colors indicating areas with higher numbers of unplumbed households. Shaded areas (in orange) indicate that sampling error is large relative to the estimate, due to the relatively small number of unplumbed households. Meehan et al. (2020) explain that the use of hexagonal areas of equal area were applied to reduce spatial bias that comes from using census tracts, which tend to mask unplumed households in urban areas while over-expressing them for some rural areas.

Source: Meehan et al. 2020

Research by Mueller and Gasteyer (2021) also found that incomplete plumbing was correlated with “age, income, poverty, indigeneity, education, and rurality.” In the United States, 5.8% of Native American households lack complete plumbing and are 19 times more likely than white households to lack indoor plumbing (Roller et al., 2019). Water and sanitation access is thus an issue of environmental injustice and an indication of the failure to secure a basic human right (Mueller and Gasteyer 2021; Gleick 1999).

3. Climate Change and the Human Right to Water and Sanitation in the United States

Access to water and sanitation remains an imperative civil rights and moral challenge in the United States (Jones and Moulton 2016; McGraw 2020; DigDeep 2021; WECR 2020). As noted earlier, an estimated 2.2 million people in the United States live without access to water and sanitation, and millions are served by water systems with Safe Drinking Water Act (SDWA) violations (Roller et al. 2019).[4] Internationally, the United Nations recognized the human right to water and sanitation in 2010 (Resolution 64/292, United Nations 2014). While many countries voted in support of the resolution and began incorporating a version of the resolution (or other statutes addressing universal water access) into their national laws, the United States abstained from the United Nations vote, has repeatedly voiced official opposition to the human right to water, and has not codified legal protection to water and sanitation access at the federal level (Gleick 2023). The United Nations has also made achieving the human right to water part of its broader "Sustainable Development Goals" (SDGs), as SDG 6 (United Nations n.d.). The purpose of SDG 6 is to help drive activities and secure resources for global action "to ensure availability and sustainable management of water and sanitation for all by 2030" (UN-Water 2021).

In the United States, while recognition of the human right to water and sanitation is not the end goal itself, creating a meaningful, legal right and obligation would establish a foundation for ensuring all people are able to meet their basic needs with dignity. Putting laws and policies in place built to protect the human rights to water and sanitation, especially at the federal and state levels would help create institutional accountability, designate responsibility, and muster the necessary resources. Both California and Virginia have acknowledged a human right to water, through a law and a resolution, respectively. While neither requires that drinking water and sanitation services be delivered to each and every household, some evidence indicates that at least in California, where the law was passed in 2012 (Assembly Bill No. 685 2012), there has been some positive change. For example, the state has established the Safe and Affordable Funding for Equity and Resilience (SAFER) program, which has an annual $130 million budget to address the water access gap in California (California EPA 2021). Still, more than one million people in California continue to lack access to water (California State Water Resources Control Board 2022).

---

[4] SDWA violations include health-based violations, monitoring and reporting violations, public notice violations, and other violations. Of these, only a subset of the health-based violations is for exceedances of health-based drinking water quality standards.

In this report, we use the term “Human Right to Water and Sanitation” to highlight the fundamental daily human need for clean, reliable water and to build on the authors’ decades of combined efforts to bring attention to this urgent issue.

To achieve the human right to water and sanitation, there are five essential components of water and sanitation services that must be met: water must be sufficient, safe, acceptable, physically accessible, and affordable (United Nations 2014; California EPA 2021). These components as applied to the US context are defined as follows:

> *Sufficient* - The World Health Organization (WHO) considers 50–100 liters (approximately 13–26 gallons) per person per day to be the minimum necessary to ensure the most basic needs. 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).
>
> *Safe* - Safe water is drinking water that meets or exceeds standards set forth by the federal SDWA, and by any additional standards established by individual states, where geographically applicable. Safe sanitation means that the waste be 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.
>
> *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.
>
> *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. Accessible sanitation is when toilets are private, located in a home, safe to visit, and available when needed.
>
> *Affordable* - In general, these services are 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, healthcare, food, and other utilities (Teodoro 2019; Feinstein 2018).

Each of these five components are key to fulfilling the human right to water and sanitation and closing the water access gap. Yet, climate change is already making it more difficult to ensure sufficient, safe, acceptable, physically accessible, and affordable water and sanitation for all.

Because water is a primary medium through which humans and the environment will experience the impact of climate change, ensuring the human right to water and sanitation must include preparing for climate change (UN-Water Expert Group on Water and Climate Change 2019). Floods, hurricanes, and other extreme weather can knock water and wastewater systems offline thereby endangering human health and the environment (Lall et al. 2018). Chronic events, such as droughts and sea level rise, do much of the same contributing to the loss of access to water supplies, impairing water quality, and permanently damaging infrastructure (Fleming et al. 2018; Payton et al. 2023).

Achieving the human right to water and sanitation by ensuring sufficient, safe, acceptable, physically accessible, and affordable water and sanitation to all people in the United States will be no small task, even without the ongoing and growing impacts of climate change. However, without the reduction of climate-altering greenhouse gases by major economies around the globe, the impacts of climate change will dramatically worsen in the coming decades and persist for generations to come (Canadell et al. 2021). Communities already experiencing tenuous, incomplete, and/or nonexistent water and sanitation access are those most at risk, because they start from a point of greater vulnerability. Households that already collect and haul water outside the home, which is physically taxing, time intensive, and often expensive, are particularly vulnerable (DigDeep 2022). For example, approximately 30% of Navajo Nation households lack running water and rely on hauled water to meet their basic daily needs (Navajo Nation Department of Water Resources 2003). Increased stress from a changing climate will mean added challenges for these communities, such as increased number of days with extreme heat, increased risk of wildfires, more intense storms, and contamination of the surface supplies and groundwater sources they depend on, to name a few.

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

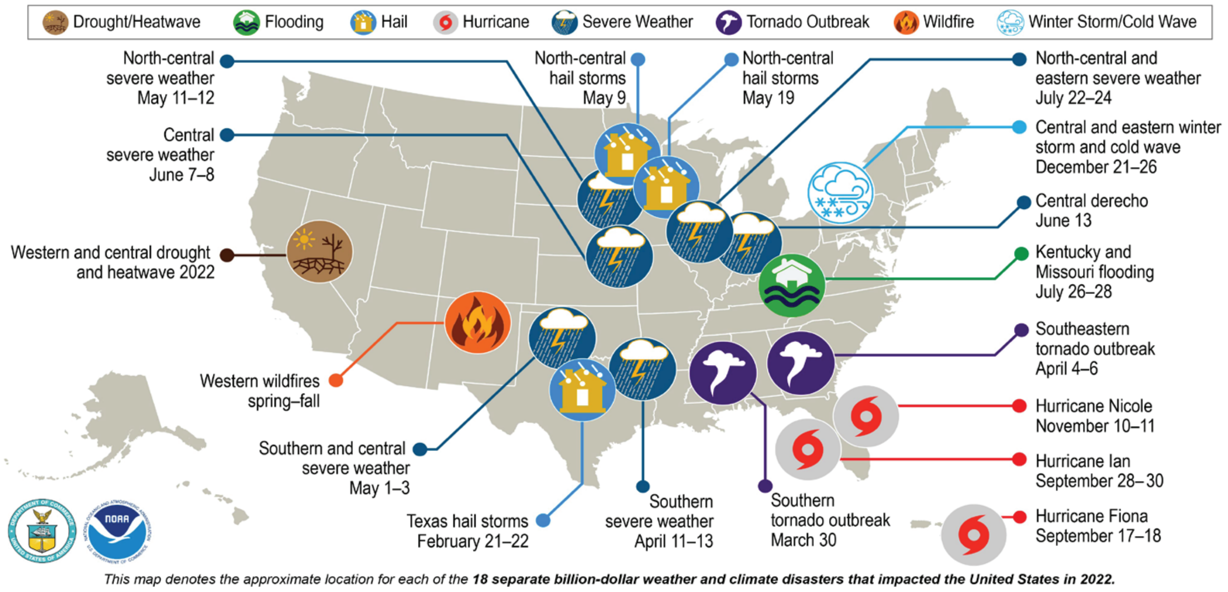

Photo provided by DigDeep

4. Six Climate Phenomena Affecting the Water and Sanitation Systems of Frontline Communities

Anthropogenic (i.e., human-caused) climate change is already affecting water and sanitation access for frontline communities. The changing climate is associated with an increase in global average temperatures and in the severity and frequency of climate extremes, including extreme temperatures, heavy precipitation events, severe storms, droughts, and major flooding events (Marvel et al. 2023). Each of these changes can affect the sufficiency, safety, acceptability, physical accessibility, and affordability of water and sanitation.

Each region of the United States will face unique challenges due to, for example, climate, geography, and socio-political factors. As the weather and climate have changed, the magnitude and frequency of disasters has grown. The Fifth National Climate Assessment (NCA5) mapped the location of the 18-billion-dollar weather and climate disasters in 2022 in the United States (Figure 3) (Marvel et al. 2023). These included droughts and heatwaves, flooding, hail and winter storms, hurricanes, wildfire, and other severe weather, including tornado outbreaks. As reported in NCA5, “[i]n the 1980s the country experienced, on average, one (inflation-adjusted) billion-dollar disaster every four months. Now, there is one every three weeks, on average” (Jay et al. 2023). Water-related billion-dollar disasters (e.g., winter storms, tropical cyclones, severe storms, flooding, drought) have followed this increasing trend (Figure 4).

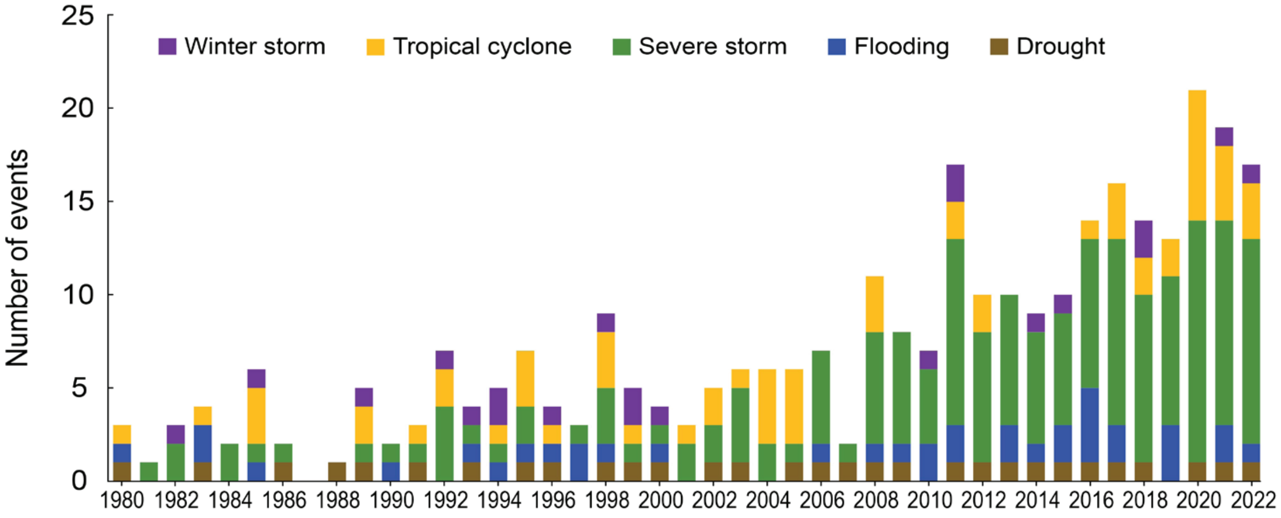
FIGURE 3. Billion-Dollar Weather and Climate Disasters (2022)



This map denotes the approximate location for each of the ***18 separate billion-dollar weather and climate disasters that impacted the United States in 2022.***

Source: Marvel et al. 2023

FIGURE 4. Water-Related Billion-Dollar Disasters in the United States (1980-2022)



Source: Payton et al. 2023

This report examines six types of extreme climate impacts affecting water and sanitation systems in frontline communities. The six major types of climate impacts we examine include: 1) extreme temperatures, 2) drought, 3) inland flooding, 4) sea level rise, 5) extreme storms, and 6) wildfires. The report does not include all climate change impacts nor all the complex interdependencies affecting water and sanitation systems and water resources, such as energy dependence, resource tradeoffs, or environmental degradation. It is also important to note that not all examples used herein to demonstrate the challenges posed by these six climate phenomena have, to date, been directly scientifically attributed to climate change.[5] We do provide ample evidence of each climate phenomena's link to climate change and relevant future projection under Earth's increasingly altered climate system, but the importance of these examples is not in their direct or indirect attribution to climate change. Rather, it is in the profound and devastating ways that extreme weather and natural events can disrupt or destroy water resources and water and sanitation infrastructure, leaving people and communities without water or sanitation access for hours, days, weeks, months, and beyond. Importantly, while we have a basic understanding of water-related climate risks, new information, better observations and data, and improvements in science continue to add to our understanding.

4.1 EXTREME TEMPERATURES

Climate change is driving an increase in the frequency, magnitude, and duration of heatwaves (Perkins-Kirkpatrick and Lewis 2020; Vose et al. 2017; Hayhoe et al. 2018; Marvel et al. 2023), and even in some rare cases, of extreme cold events in mid-latitude regions in the Northern Hemisphere (Cohen et al. 2021).[6] The US Department of Homeland Security broadly defines an extreme heat event (also referred to as a "heatwave") as a period of high heat and humidity with sustained temperatures of about 90°F for a minimum of two to three days (US Department of Homeland Security 2022). There has been a significant increase in heatwaves in almost all parts of the world since the 1950s, largely characterized by longer duration events (Perkins-Kirkpatrick and Lewis 2020). In the 50 largest US cities, the average number of heatwaves has doubled since the 1980s, and the heatwave season has lengthened from ~40 days to ~70 days (Marvel et al., 2023).

The National Weather Service (NWS) is similarly broad in its definition of extreme cold but does not give a specific temperature threshold (National Oceanic and Atmospheric Administration n.d.). They note that certain factors, such as wind chill, can contribute to impacts from extreme cold events. Climate change is intensifying temperature extremes and potentially altering atmospheric circulation, making extreme temperature events, particularly extreme heat events, more common (Vose et al. 2017; Seneviratne et al. 2021; Marvel et al. 2023). These extreme temperature events are expected to increase in magnitude and become more common every decade (Thompson et al. 2022).

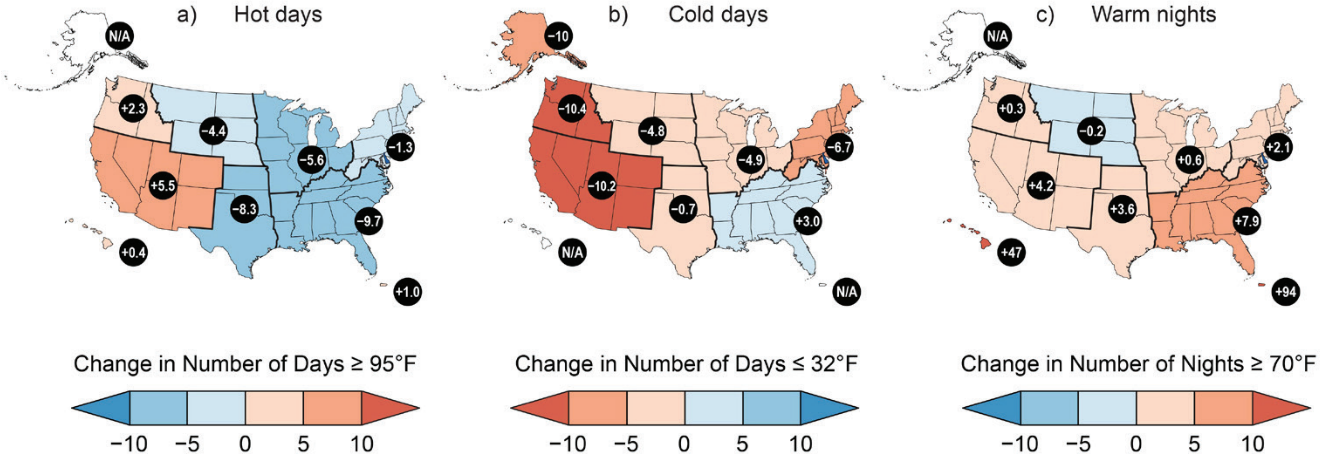
---

[5] Attributing climate change to any single weather event is challenging for scientists because there have always been extreme weather events, and it requires complex and uncertain statistical analyses based on available long-term data. Attribution science is a discipline that has developed over recent decades that seeks to quantify how much climate change has played a role in any specific extreme weather event (Cho 2021). Attribution science is best applied when there are long (100 years or more) observational records of the type of event being studied in the location where it occurred (not always available). It is also better at quantifying attribution of climate change for temperature-related events, like heatwaves, but not as good at quantifying attribution to extreme precipitation events due to modeling constraints (Cho 2021). In other words, just because an event has not been scientifically directly attributed to climate to date, it does not necessarily mean it was not a climate change phenomenon.

[6] Cohen et al. (2021) uses observations and models to demonstrate how changes in the Arctic due to climate change are likely an important driver of a chain of events that involve "stratospheric polar vortex disruption," which ultimately can result in extreme cold events in the mid-latitudes of the Northern Hemisphere.

According to the United States National Climate Assessments, all regions of the United States have shown a change in the length of the frost-free season, which occurs between the last freeze in the spring and the first freeze in the fall (Vose et al. 2017; Marvel et al. 2023). It also reports that average annual temperatures, which incorporate extreme heat and cool, are projected to rise by about 2.2°F relative to 1986–2015 levels by mid-century. Figure 5 shows observed changes in hot and cold extremes over the period of 2002–2021 relative to 1901–1960 (or 1951–1980 for Alaska and Hawaii) (Marvel et al. 2023). Figure 6 shows projected changes (relative to 1851–1900) in annual average temperatures across the United States under different global warming levels (1.5°C/2.7°F, 2.0°C/3.8°F, 3.0°C/5.7°F, and 4.0°C/7.6°F). Extreme high temperatures are projected to increase even more than average temperatures (Vose et al. 2017).

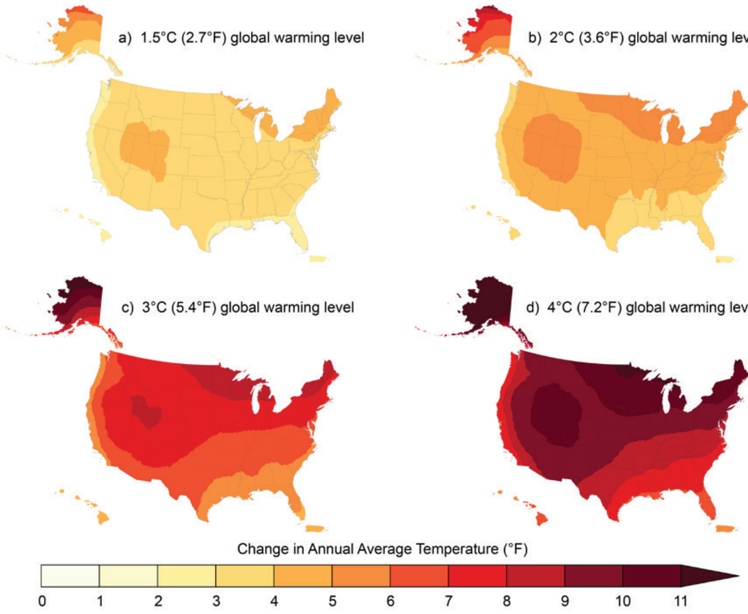
FIGURE 5. **Observed Changes in Hot and Cold Extremes**



Note: This figure shows the observed change over the period of 2002–2021 relative to 1901–1960 (1951–1980 for Alaska and Hawaii).

Source: Marvel et al. 2023

FIGURE 6. Projected Changes in Annual Average Temperature (°F) for Various Global Warming Levels



Source: Marvel et al. 2023

4.1.1. Impacts of Extreme Heat

Extreme heat can have direct and indirect impacts on water supply and water systems. One immediate, direct impact of extreme heat is to cause increased evaporation. For communities dependent on surface water supplies, such as from a reservoir, increased evaporation can reduce water supply availability, making it challenging for water systems to deliver water in sufficient quantities. In the Colorado River Basin, climate change is increasing evaporative losses in two of the largest water-supply reservoirs, Lake Mead and Lake Powell (the reservoirs behind Hoover Dam and Glen Canyon Dam, respectively) (Osezua et al. 2023), adding stress to an over-allocated water system that supplies water to 40 million people. Increasing temperatures and extreme heat events are also contributing to harmful cyanobacterial blooms (Paerl and Huisman 2009), which can make the water unsafe to drink or use even after treatment (Zamyadi et al. 2012). In places where open water bodies are overloaded with nutrients, like phosphorus from fertilizer runoff, warming temperatures support increased growth in harmful algal blooms (Paerl and Huisman 2009). Research by Chapra et al. (2017) projects that harmful cyanobacterial algal blooms are likely to increase as water temperatures increase in reservoirs across the contiguous United States; changes in air temperature are the primary driver for changes in water temperature in their model.

While outside of the United States, recurring cyanobacterial algal blooms in Lake Taihu in China offer one recent documented example of how heatwaves contribute to toxic algal blooms and can lead to a loss of access to drinking water for millions of people. In the summer of 2022, three heatwaves in China were linked to a harmful cyanobacteria bloom in the lake, which supplies water to approximately 20 million people (Li et al. 2023). Researchers reported how the cumulative effects of these heatwaves, which included high air temperature, low wind speed and rainfall, and high solar radiation, promoted the growth of harmful cyanobacteria blooms. Water suppliers in the region have been challenged by these blooms for more than a decade, causing disruptions in their ability to provide water to their communities for days and weeks at a time (Qin et al. 2019).

An indirect impact on water supplies from extreme heat is how it affects water use. During extreme heat events people tend to use more water for watering outdoor landscapes, keeping cool, or staying hydrated. For centralized water systems, temperature spikes can lead to peak demand, putting strain on the entire system (Shafiei Shiva and Chandler 2020), making it more challenging for water utilities to deliver sufficient quantities of water. During a heatwave in August of 2023, the City of Carlsbad, New Mexico, issued mandatory outdoor water restrictions to help protect their water supplies (Smith 2023). While this did not likely cause a loss of water access for Carlsbad households, it shows how water utilities have acted in response to heat waves by placing restrictions on water use.

Another indirect effect of extreme heat can be increased evapotranspiration, which creates dryer conditions across the landscape, increasing the risk of wildfire (White et al. 2023). In the Pacific Northwest, the start of summer 2021 had a record-breaking heatwave, with many locations breaking all-time maximum temperature records by more than 5°C (9°F) (White et al. 2023). Research by White et al. (2023) details the immediate and longer-term impacts from the heatwave and extreme temperatures, including how it directly contributed to drier, warmer, and windier conditions that spawned large fires during the event and after it had subsided. Wildfires are discussed further in Section 4.6.

The impacts of extreme high temperatures disproportionately affect frontline communities and can exacerbate existing disparities in water and sanitation access, as well as increase the risk of heat-related illnesses and other health impacts (Shindell et al. 2020). Heatwaves increase the need for water access to aid in cooling and hydration to avoid heat-related illness and death (Shindell et al. 2020). Older adults are already at increased risk of dehydration, even under normal circumstances (National Council on Aging 2021). People experiencing homelessness are also at increased risk of heat-related illnesses, in part due to lack of access to sufficient drinking water (Every et al. 2021). Dehydration and other heat-induced illnesses are also a major risk for laborers exposed to extreme heat (Levy and Roelofs 2019). Workers with few rest periods and limited access to water and places to cool off are at especially elevated risk (Kjellstrom et al. 2018).

4.1.2 Impacts of Extreme Cold

Extreme cold events can cause damage to water supply and sanitation systems, cutting off access for the people served by those systems, especially in unprepared or un-weatherized geographies. For example, in Jackson, Mississippi, the 2021 severe winter storm that brought extreme cold temperatures and power outages to the region led to burst water mains and pipes, disrupting service delivery for weeks (Fentress and Fausett 2021). In this case, 70% of the city’s residents were still under boil-water advisories a month after the storm (Fentress and Fausett 2021). In the Midwest, where winter snow is more common, reduced winter snowpack from lower-than-average precipitation caused septic drain fields to freeze and fail during extreme low-temperature events (Calabretta et al. 2022). In this region, the combination of cold temperatures along with the change in snowfall have combined to alter the impact of cold events on septic tank infrastructure, leading to failure.

Cold temperatures caused widespread electricity grid failures, power shortages, and water-system breakdowns in Texas during Winter Storm Uri in 2021 (Igini 2022). Municipal systems that lost grid power and were without backup power were unable to treat or distribute water (Glazer et al. 2021). Consequently, approximately 49% of Texans (more than 14.4 million households across 190 counties) had water service disrupted (Watson et al. 2021; Glazer et al. 2021). Nearly 264,000 Texans lived in areas where water systems were completely nonoperational (Wang et al. 2022). In general, disruptions in water service lasted longer for those served by small water systems (serving 25–500 people) (Glazer et al. 2021).

Extreme cold also has impacts on water quality. In the case of Winter Storm Uri, broken distribution pipes caused a loss of system pressure across more than 680 water systems that, in turn, had to issue boil-water notices due to potential for contamination. These boil notices affected more than 16 million people (Samuels 2021; Texas CEQ 2021; Wang et al. 2022), likely the largest boil-water notice event in US history (Glazer et al. 2021). In surface-water bodies, like lakes and reservoirs, extreme cold can disrupt the nutrient-cycling processes, causing changes to water quality that can lead to bacterial growth (Wang et al. 2022). And while not only used for extreme cold events, deicing products used on roads, driveways, parking lots, and other places can lead to increased salinity and contamination in surface water and groundwater, compromising water safety (Perera et al. 2013).

> The impacts of extreme high temperatures disproportionately affect frontline communities and can exacerbate existing disparities in water and sanitation access, as well as increase the risk of heat-related illnesses and other health impacts.

4.2 DROUGHT

Drought is a prolonged period of abnormally dry conditions, typically characterized by a lack of precipitation causing a water shortage. Droughts can be classified as meteorological, hydrological, agricultural, socioeconomic, or ecological, depending on the cause and impact (National Drought Mitigation Center n.d.).[7] Droughts can occur in any climate or region, and their severity can range from mild or “abnormally dry” (D0) to exceptional (D4) depending on factors such as the length of time without rainfall, the intensity of heat and wind, and the availability of water reserves, among other complex factors (National Drought Mitigation Center n.d.).

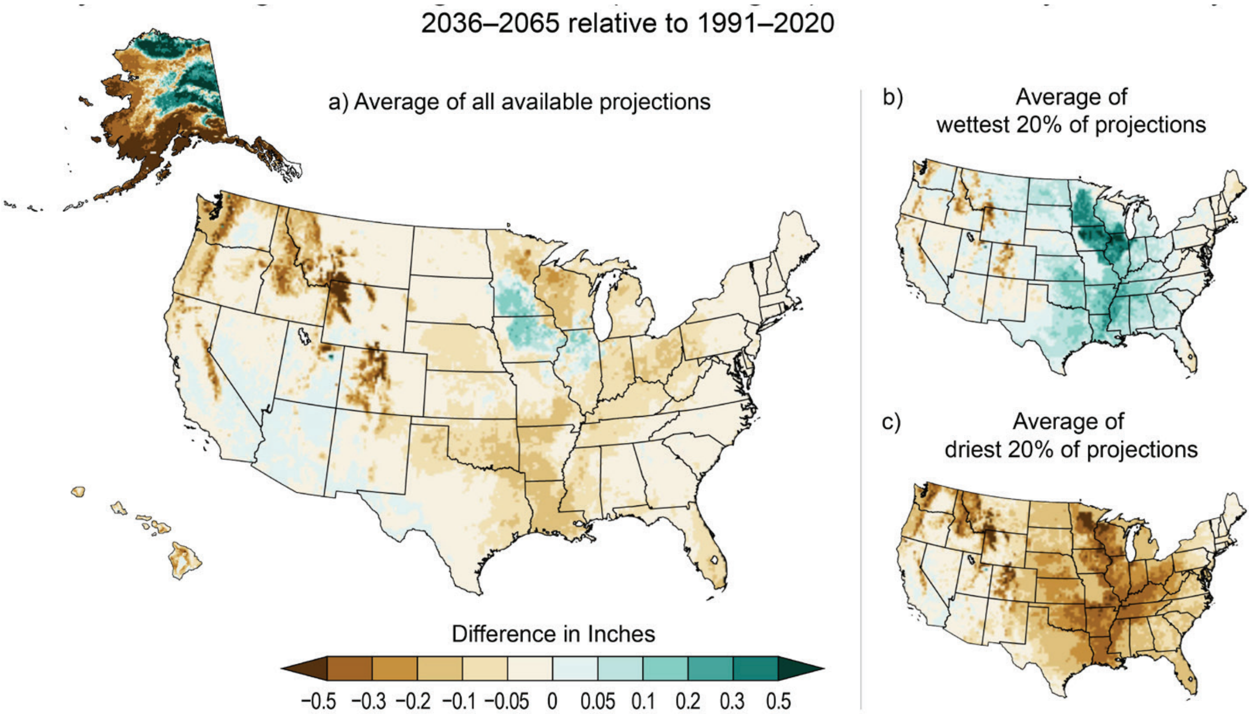
Climate change is increasing the frequency, severity, and duration of droughts in many regions of the world by altering precipitation patterns, increasing temperatures, and decreasing soil moisture (Pörtner et al. 2022). While the focus of drought often centers on the lack of precipitation, the role of warmer temperatures is important to understand (Overpeck and Udall 2020). In the United States, drought exacerbated by climate change is largely a result of surface soil moisture deficits from

---

[7] See https://www.drought.gov/what-is-drought/drought-basics#types-of-drought for more on how the different drought types are defined.

increased evapotranspiration because of hotter temperatures, though this varies regionally (Wehner et al. 2017; Marvel et al. 2023). Of particular concern is the co-occurrence of high temperatures and dry periods from a lack of precipitation (Mann and Gleick 2015) as well as more frequent and longer periods of low-to-no precipitation compared to historical averages (Siirila-Woodburn et al. 2021). Throughout the United States, future decreases in soil moisture combined with warming temperatures are expected to increase the intensity and extent of drought impacts (Figure 7) (Payton et al. 2023). Much of the United States is now vulnerable to “flash droughts” that can happen in a matter of days through some combination of extreme heat and/or wind speeds with a lack of rainfall (Marvel et al., 2023). Drought exacerbated by climate change will continue to have complex, interacting effects on ecosystems and the humans that depend on them (Clarke et al. 2018; Mach et al. 2023).

Figure 7. Projected Change in Average Summer Soil Moisture, Middle of the 21st Century, Intermediate Emissions



Note: Graphic shows the (a) average difference in inches in soil moisture across all available projections, as well as the average of the (b) wettest and (c) driest projections.

Source: Payton et al. 2023

Anthropogenic (i.e., human-caused) climate warming is increasing so-called “hot drought” and more arid conditions throughout an expanding area of the United States (Overpeck and Udall 2020). However, there are regional differences in drought occurrence, duration, and causes. The Upper Missouri River Basin experienced the worst drought in the instrumental records from 2000–2010, and tree-ring records indicated it matched or possibly surpassed any droughts over the last 12 centuries (Martin et al. 2020). California and the Southwest United States are particularly prone to decadal persistence of droughts, and they have been experiencing increased drought severity in recent decades (Williams et al. 2022). During the period from 2000–2021, the Southwest experienced the driest 22-year period in at least 1,200 years, and climate change is expected to increase the risk and severity of "megadroughts" in western North America (Williams et al. 2022; Cook et al. 2022). Higher global temperatures are intensifying and amplifying droughts that are resulting in tangible water shortages for ecosystems and human use in California watersheds and the Colorado River Basin (Gonzalez et al. 2018). During the period 2000–2014, Colorado River streamflow was 19% lower than the 20th century average (Marvel et al., 2023).

The increased drought risk in the Southwest is exacerbated by a warming climate that causes vapor pressure deficit (VPD) (Crownhart 2021). VPD is defined as a difference in the amount of water vapor in the air versus the amount of water vapor that it can hold. The hot air of the desert Southwest can hold more moisture than cold air, so as temperatures rise, more water will evaporate. The probability of VPDs such as those experienced in the Southwest in 2020 occurring during any given year was 0.4%, or a 1-in-200 years event; yet, with the onset of climate change, by 2030 such deficit events are expected to be a 1-in-10 years event in the Southwest (Crownhart 2021). A study of recent historical data (1979–2013) and future projections found higher temperatures will lead to greater evaporation and loss of moisture from surface water and soils, as well as an expected nationwide increase in summer VPD by as much as 51%, resulting in "continental-scale drying of the United States atmosphere," especially in regions where water availability is already low (Ficklin and Novick 2017).

Mountain snowpacks have historically represented significant natural reservoirs, and through runoff they supply rivers, lakes, and groundwater recharge, as well as constructed reservoirs that provide hydropower and water for communities and irrigators. In the Western United States, researchers have estimated that approximately half of all runoff is derived from snow melt (Li et al. 2017). Water from snow melt across the Western United States is expected to decline approximately 25% by 2050, and low-to-no snow periods may become persistent within 35 to 60 years under a "business as usual" greenhouse gas emissions scenario (Siirila-Woodburn et al. 2021).[8] Snowpack (measured as snow water equivalent (SWE), i.e., the amount of water in snowpack) in the Upper Rio Grande Basin has already decreased compared with the historical average from 1958–2015, with April 1 SWE having decreased by approximately 25% (Chavarria and Gutzler 2018). In the Upper Colorado River Basin (UCRB) scientists found that annual mean discharge has decreased by 9% per degree Celsius (1.8°F) of warming (Milly and Dunne 2020). They concluded that warming has increased the sublimation of snow directly to the atmosphere, causing loss of snow cover, thereby reducing albedo (surface reflectivity) and increasing the temperature of the ground surface (which further increases evaporation, creating a feedback loop).[9] Climate scenarios indicate stream flows in the UCRB could decrease by nearly 30% by 2050 (Miller et al. 2021). The projected loss of snowpack and runoff will have potentially catastrophic consequences in snow-fed basins that will affect all water users (Siirila-Woodburn et al. 2021; Milly and Dunne 2020). Furthermore, diminished and increasingly ephemeral snowpacks that melt earlier in the season have implications for groundwater recharge and surface flow dynamics (Siirila-Woodburn et al. 2021).

---

[8] Intergovernmental Panel on Climate Change "business as usual" scenario assumes that no greenhouse gas mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted.

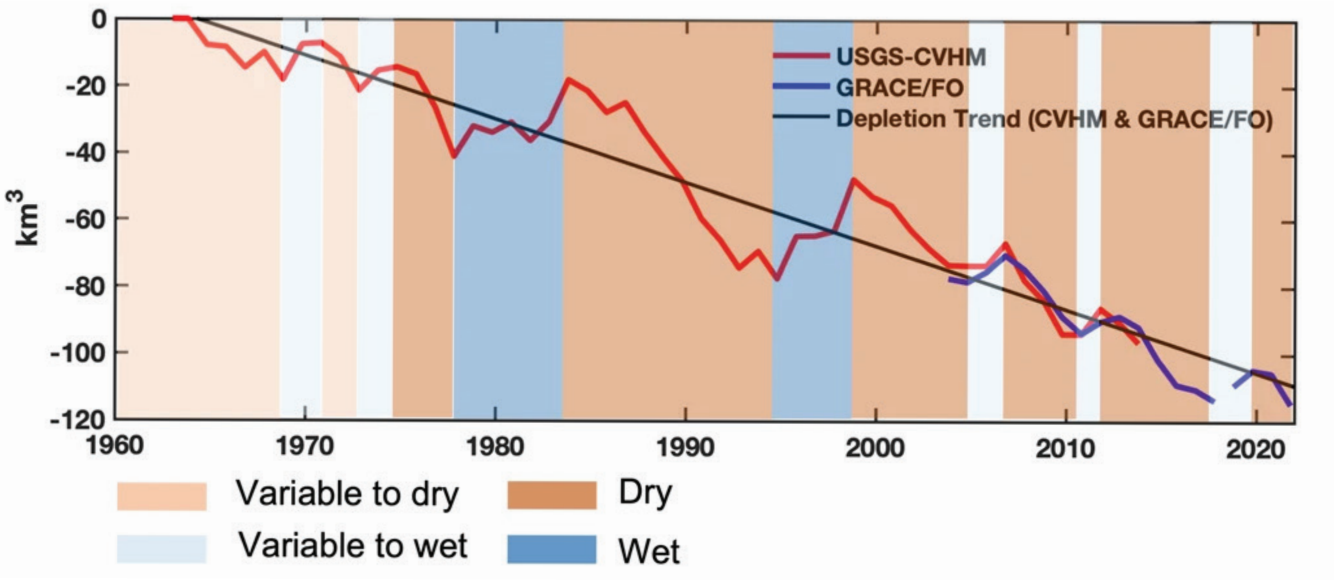
[9] Albedo is a measure of the reflectivity of a surface. Snow and ice generally have higher albedo than darker surfaces like exposed ground.

4.2.1 Groundwater and Drought

Groundwater systems already provide a substantial amount of water supply for both agricultural and domestic needs in different parts of the country, but during droughts when surface water resources are diminished, groundwater use often increases to meet demands (Pauloo et al. 2020). Increasing drought severity in the Western United States increases overall water demand for irrigation and, in turn, accelerates groundwater depletion (Scanlon et al. 2012). This can increase the time required to replenish or recharge aquifers (Russo and Lall 2017). As climate changes increase drought, or changes the timing or intensity of precipitation timing, magnitude, and location, recharge of groundwater resources can be even further reduced (Döll 2009; Meixner et al. 2016), diminishing the physical accessibility of water resources.

Because climate change affects both the supply of water for groundwater recharge and the demand for groundwater (Lall et al. 2018; Amanambu et al. 2020), the overexploitation and depletion of groundwater resources can negatively impact water supply systems that rely on them (Bostic et al. 2020; 2023). In California, where around 1.5 million Californians rely on domestic wells for drinking water, a combination of drought and groundwater overdraft has led to the drying of wells, land subsidence, and the decline in access to water for many frontline communities (Pauloo et al. 2020; Galloway and Burbey 2011). In 2021 and 2022, amidst a nearly statewide drought, 2,493 domestic well water outages were reported to the state, the majority from inland regions, such as the Central Valley (California Department of Water Resources 2023). Figure 8 shows the precipitous long-term decline of groundwater volume in California's Central Valley, despite modest recharge during occasional wet years (Liu et al. 2022).

FIGURE 8. **Yearly Cumulative Groundwater Losses in California's Central Valley**

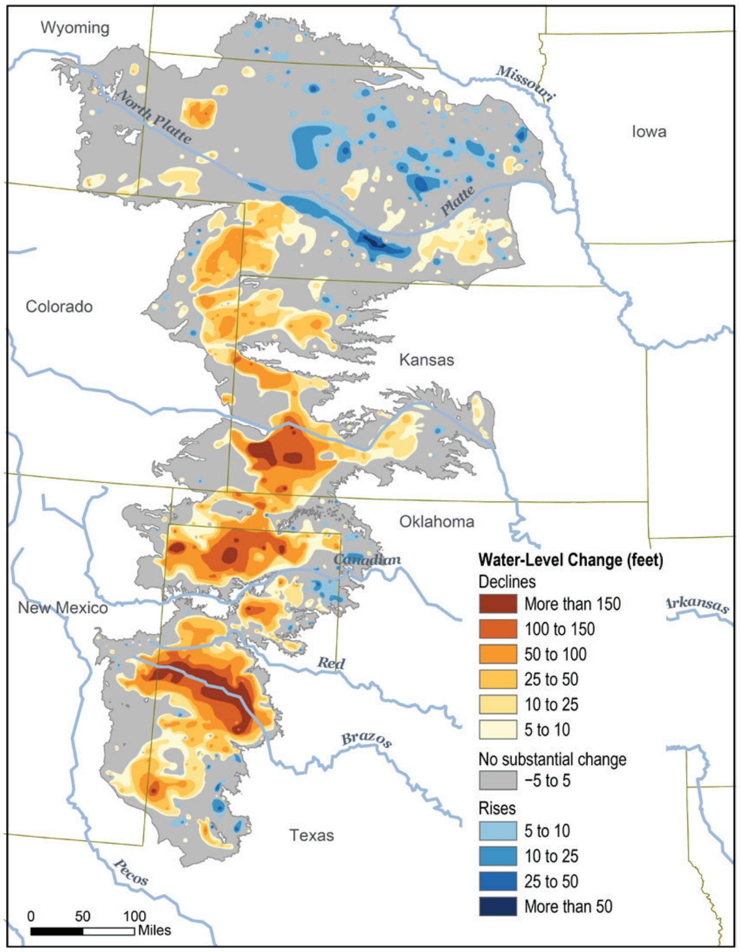


Note: Groundwater losses combining the USGS's Central Valley Hydrologic Model (CVHM) and the GRACE/FO estimates since 1962. The black line represents the overall groundwater depletion from 1962 to 2021 calculated by combining the CVHM and GRACE estimates.

Source: Liu et al. 2022

In the Central United States, depletion of the Ogallala Aquifer is also happening at rates faster than natural recharge, although there is regional variation in rates of depletion (Winter and Foster 2014). Figure 9 shows the regional changes in water level across the Ogallala Aquifer from predevelopment to 2015 (Gowda et al. 2018).

FIGURE 9. Ogallala Aquifer Water-Level Change from Predevelopment to 2015



Source: Gowda et al. 2018

The depletion of groundwater exacerbates drought risk (Lall et al. 2018; Payton et al. 2023), especially for disadvantaged communities dependent on shallow wells for water supply (London et al. 2018). Some of the greatest risks to communities dependent on the Ogallala Aquifer are due to increased costs for pumping that are associated with dropping groundwater levels and costs for extending existing or digging new groundwater wells (Tidwell et al. 2016). While many questions remain about exactly how climate change will impact groundwater in specific places and times, a synthesis of 40 studies indicates it will decrease groundwater recharge, storage, and levels, particularly in already arid areas (Amanambu et al. 2020).

4.2.2 Drought Impacts on Water Quality

In the United States, droughts are negatively affecting drinking water availability, water quality, and public health (Lall et al. 2018; Payton et al. 2023). Droughts change the quality of well water, along with groundwater depletion through overdraw, which also has been linked to the degradation of groundwater quality (Levy et al. 2021). In a US Geological Survey study of 30 years of data, scientists found that increased pumping from wells during a drought can pull shallow, contaminated groundwater down to depths commonly tapped for the public drinking water supply (Levy et al. 2021). Furthermore, droughts can increase the amount of contaminants and pollutants in shallow well water (Pauloo et al. 2020).

Declining groundwater resources disproportionately affect frontline communities in the California Central Valley, the Southwest United States, and other regions. In eastern Oregon, decades of groundwater degradation in Morrow and Umatilla counties from nitrate contamination have left hundreds of domestic wells at risk (Oregon Secretary of State and Oregon Audits Division 2023). This study from eastern Oregon also noted that populations in both counties experience a higher rate of poverty and are comprised of a higher proportion of those who identify as Hispanic or Latino compared to the state as a whole. Research has shown that throughout the United States, domestic well users are at elevated risk of arsenic exposure during droughts, raising considerable public health concerns (Lombard et al. 2021).

4.2.3 Disproportionate Drought Impacts

Drought also takes a substantial economic toll on communities. From 1980–2022, damage from drought and related heatwaves resulted in $399.4 billion in total costs to the nation along with 4,275 deaths[10] (a death toll second only to tropical cyclones) (NOAA NCEI 2022). One way drought disproportionately impacts frontline communities economically is through the increasing cost of water. Climate change and droughts may contribute to a rise in the cost of water if, for example, a water utility must purchase a more expensive water supply, pump groundwater from deeper in an aquifer, or add treatment processes to degraded water supplies (Feinstein et al. 2017). When water is scarce, the cost of water may increase to reflect its value, particularly in existing arid regions or in areas with rapidly growing populations (Patterson and Doyle 2020). Households that have their own water source may also be required to spend more money on obtaining and treating water during a drought. In both cases, affordability of water may inhibit access for those unable to afford the cost of rising water rates or new treatment.

The report *Safeguarding Water Affordability* indicates that the combination of aging infrastructure, changing customer bases, regulatory compliance, and climate change ultimately necessitates higher rates overall, and the authors encourage efforts to ensure affordability for vulnerable and/or low-income communities (Bipartisan Policy Center 2017). The EPA Climate Change Impacts and Risk Analysis project found that global inaction to mitigate greenhouse gases could add considerable financial costs due to damage to water quality, urban drainage, and water supply in the United States. For example, water-quality damages are expected to increase by over $3.2 billion in 2100. Under a greenhouse gas mitigation scenario, damages are reduced by over 82%, avoiding up to $3

---

[10] Deaths attributed to droughts are the result of heatwaves, though not all droughts are accompanied by extreme heatwaves (NOAA NCEI 2022).

billion in costs (US EPA 2015a). If these estimates are accurate, the failure to reduce greenhouse gas emissions leads to climate changes that place a significant future cost burden on utilities and will require extensive investment in conservation, supply logistics, and treatment.

Droughts have variable impacts on different water users and communities even within the same watershed (McNeeley 2014). For example, over the period of 2008 to 2018, water storage and supplies in the upper Tuolumne watershed serving urban water users in economically well-off areas of Northern California were not affected by drought; but supplies to agricultural and urban users in lower-income areas in the Central Valley were cut by 30% (Stewart et al. 2020). Over the period from 2012 to 2016, the Pacific Institute found that 76% of drought-impacted public water systems in California were small, serving 1,000 connections or less, consistent with the overall percentage of small systems found in the state (Feinstein et al. 2017). They also found that “a large proportion of drought-impacted public water systems and household outages were in Disadvantaged and Cumulatively Burdened Communities [and] of the 92 drought-impacted public water systems for which we know the location, two-thirds served a Disadvantaged Community, and nearly one-third served a Cumulatively Burdened Community.”[11] These water-supply outages from drought leave communities and households that once had it without water access, providing an example of how extreme climate events can result in backsliding.

Indigenous communities experience some drought impacts similar to other marginalized communities, but they are also affected uniquely and disproportionately based on geography and the legacies of settler colonialism (Jantarasami et al. 2018; McNeeley 2017; Whyte 2018; McNeeley et al. 2018; Whyte et al. 2023). The Metlakatla Indian Community of Southeastern Alaska relies on local lakes to supply municipal water and generate hydropower. Chester Lake has not maintained levels adequate to meet the demands of municipal water needs and generate electricity, which caused the Tribe to cease operations at the hydropower plant and switch to diesel generators, a less sustainable and more costly option (Scott et al. 2017). The Tribe’s Climate Change Adaptation Plan states that the inability to secure supply to meet multiple water needs is due to “a shift in precipitation coupled with warmer winter temperatures that results in little to no snowpack, coupled with increased energy demands” (Scott et al. 2017).

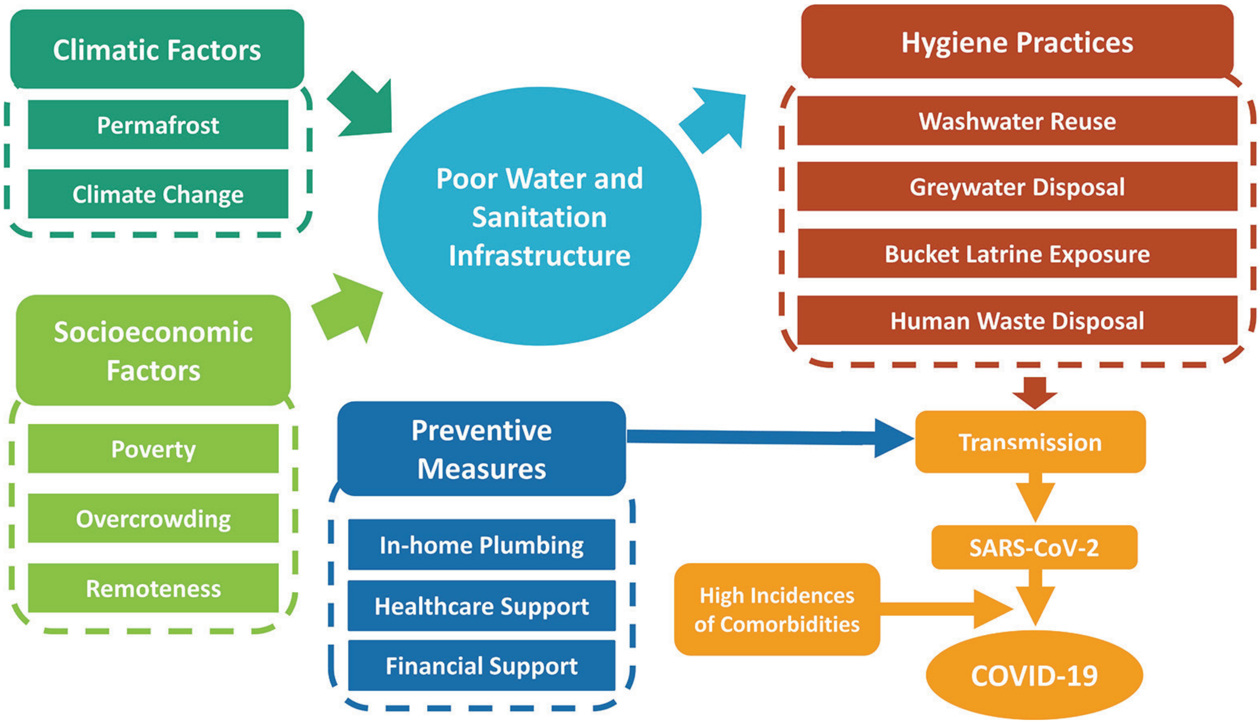
Indigenous communities are often located in rural areas where critical water infrastructure may not exist or may be located a considerable distance away, making hauling water to their homes or access to alternative water sources essential for daily life (Status of Tribes and Climate Change Working Group 2021; Roller et al. 2019). On the Navajo Nation, droughts are threatening already limited water and sanitation access, where approximately 30% of households do not have running water or indoor plumbing and must rely on hauling water from distant sources and on outhouses or inadequate septic systems (Lovato 2022; Roller et al. 2019). Many Navajo families on the reservation rely on water haulers to deliver water to their homes from off-reservation sources, which can have significant health and economic implications. Many also spend considerable time and money on water and sanitation-related activities and restrict personal water use due to cost and challenges to access (DigDeep 2022; Roller et al. 2019).

---

[11] Feinstein et al. (2017) defines Disadvantaged Communities as those that have a median household income of less than 80% of the state median. They define Cumulatively Burdened Communities as those that rank in the top quarter of census tracts in the state for environmental burdens and socioeconomic vulnerability.

Households without adequate water and sanitation access are at increased risk for waterborne illnesses and infectious diseases such as COVID-19 (Eichelberger et al. 2021). In some remote Alaska Native communities, residents already struggled to secure sufficient water supplies for hygiene and to protect their health, leaving them vulnerable to transmission of COVID-19 (Figure 10) (Eichelberger et al. 2021). During times of drought, these health risks are elevated with few alternatives for access to clean water supplies in such remote locales.

FIGURE 10. Context in Remote Alaskan Communities that Influence Transmission of COVID-19



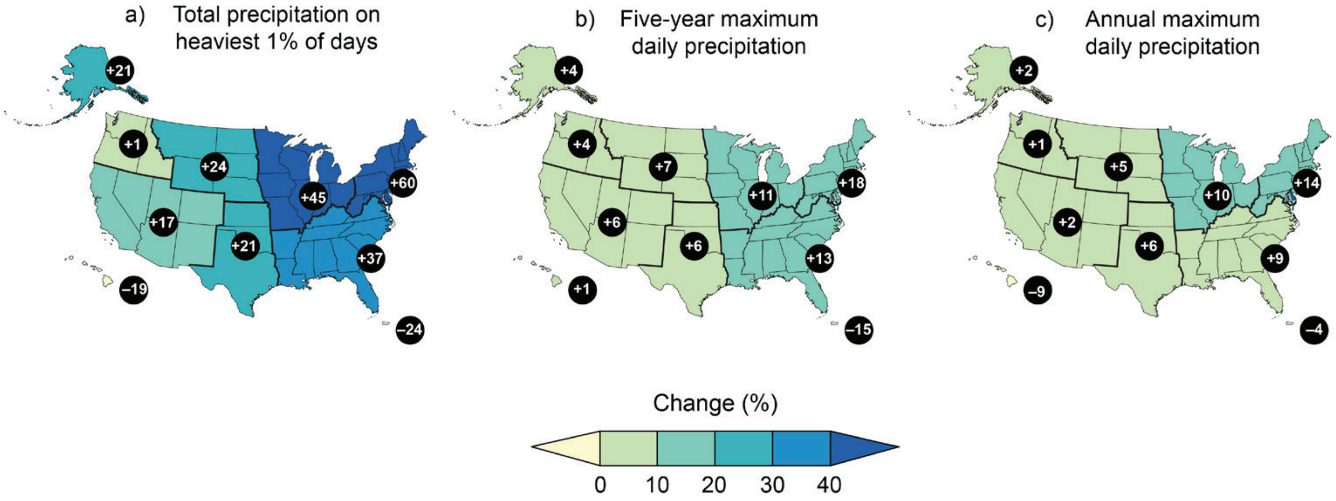
Source: Reprinted from Science of The Total Environment, Vol 776, Eichelberger et al., Implications of inadequate water and sanitation infrastructure for community spread of COVID-19 in remote Alaskan communities, Copyright (2021), with permission from Elsevier.

Droughts challenge even those communities that have been proactive in planning. El Paso, Texas has invested in “drought-proofing” water systems, increasing public awareness of water use, and wastewater recycling and desalination technologies (Crownhart 2021). However, Crownhart reported that even El Paso’s careful plans are being challenged by newly intense droughts as solutions get harder, more complex, and more expensive to implement. Crownhart stated that in October of 2021, after over 100 years serving as the area’s water supply, Elephant Butte Reservoir in New Mexico was at just 5% capacity as a direct result of severe drought conditions from January 2020 to August 2021, a 1-in-50 years event. This example demonstrates how even communities with robust water management practices that try to incorporate climate change can still be at risk from extreme events.

4.3 INLAND FLOODING

Inland flooding occurs when the volume of water overcomes the capacity of natural or built drainage systems to absorb and move the excess water (US Climate Resilience Toolkit 2023). It often results from periods of extreme precipitation or a landfalling coastal storm that brings many days of consecutive rainfall (Fleming et al. 2018; Leung et al. 2023, Marvel et al. 2023).[12] Inland flooding can also occur after rapid snowpack melt or failure of dams or levees. Observed increases in the total annual precipitation falling in the heaviest 1% of events since the 1950s and for two other metrics of extreme precipitation (five-year maximum daily precipitation and the annual maximum daily precipitation) have been found for all regions in the lower 48 states and Alaska (Figure 11) (Marvel et al. 2023; Kunkel et al. 2020). These extreme precipitation events are major contributors to inland flood and flash flood risks (US Global Change Research Program n.d.). According to the Fifth National Climate Assessment, "[t]here is robust evidence that human-caused warming has contributed to increases in the frequency and severity of the heaviest precipitation events across nearly 70% of the US." (Marvel et al. 2023).

FIGURE 11. Observed Changes in the Frequency and Severity of Heavy Precipitation Events



Note: These maps show three measures of extreme precipitation including (a) total precipitation failing on the heaviest 1% of days, (b) daily maximum precipitation in a 5-year period, and (c) the annual heaviest daily precipitation amount over 1958-2021. Numbers in black circles depict percent changes at the regional level.

Source: Marvel et al. 2023

Flooding is among the most frequent and costliest natural disasters in the United States (Federal Emergency Management Agency 2022) with an annual average cost of $32.1 billion, and costs are projected to rise with warming global temperatures (Wing et al. 2022). Between 1980-2022 flooding cost the nation $187.7 billion (NOAA NCEI 2022). Wing et al. also estimated that flood risk in the United States could increase by an average of 26.4% by 2050 due to climate change alone (depending on future greenhouse gas emissions levels). The same study identified that this future

---

[12] Scientists define extreme precipitation caused by climate change in different ways, but generally it refers to "a greater-than-normal amount of rainfall received at a certain time" (Yin et al. 2022).

flooding will disproportionately impact Black communities (with at least 20% Black population) at twice the rate of neighborhoods that are less than 1% Black. They point to hotspots of flood damage in coastal Louisiana, the inland Northeast, Appalachia, and rural counties of the Pacific Northwest and Northern California. Flooding can be costly and damaging to water utility infrastructure and operations (US EPA 2023b), which also disproportionally burdens frontline communities.

While inland flooding is largely attributed to precipitation events and extreme weather, flooding also can be the result of, or exacerbated by, aging and deteriorated infrastructure, such as levees and dam failure. The United States is home to over 91,000 dams, thousands of which are deficient and have high hazard potential (American Society of Civil Engineers 2021). The number of high-hazard dams where loss of life from dam failure is probable has increased by almost 20% in the last 10 years to over 16,000 (Association of State Dam Safety Officials 2023). The Association of State Dam Safety Officials indicates that increased drought and flooding from climate change make dam safety essential for flood protection, as well as capturing water when available or in excess and providing it downstream when needed.

In New York City, aged water infrastructure and poorly equipped storm drainage systems have resulted in sewage backups (Kaysen 2021). New York City is facing this issue despite $20 billion invested in climate resilience measures that include improved stormwater management since Superstorm Sandy in 2012 (City of New York 2021; Kaysen 2021). During Hurricane Ida in 2021, sewer mains backed up into people’s homes, resulting in two to three feet of standing sewage and tens of thousands of dollars in cleanup costs per household (Kaysen 2021). These impacts can disproportionately effect low-income communities and communities of color, such as in South Jamaica, Queens, where the residents are predominantly Black and Latino and some homeowners experience sewer backups every few months (Scott 2022). In September 2023, an extreme rain event caused flash flooding in streets and basements across the city, and the governor declared a state of emergency (Wilson and Meko 2023). In a neighborhood between the border of Brooklyn and Queens that is not connected to a sewer system, a resident reported that her building was “collapsing from water damage” (Wilson and Meko 2023). Climate change will only worsen these types of inequities (Marvel et al. 2023; Payton et al. 2023).

Jackson, Mississippi provides another illustrative example of the threat to water access for frontline and impoverished communities threatened by a combination of climate change, flooding, and aged, under-funded, and improperly maintained water infrastructure. In August 2022, news outlets reported that as many as 180,000 people in and around Jackson found themselves without safe water, resulting in emergency distribution of bottled water and tanker trucks (Trotta 2022). This reportedly occurred after system pump failure and a month-long boil-water advisory that was complicated by historic torrential rains (NOAA National Centers for Environmental Information 2022) and the cresting of the Pearl River over its banks (Trotta 2022; Grant 2022). Critical water-treatment infrastructure was comprised, causing drops in water pressure and leaving residents without water that was safe for drinking or bathing. Officials at the time warned the problem would persist “indefinitely” (Trotta 2022; Landen 2022). Public schools had to shift to online learning again (post COVID-19 pandemic era of quarantining and remote learning), and hospitals had to rely on portable restrooms (Rojas 2022). Jackson’s mayor stated that the cost to address just the immediate issues exceeded $1 billion, and billions more were needed to address the chronic issues faced by the city’s system (Landen 2022; Fentress and Fausett 2021; Grant 2022). Jackson is a cautionary tale as these types of neglected systems are increasingly more vulnerable to the hotter, wetter future that climate change will bring (Neuman 2022).

Inland flooding is also a challenge in small and rural communities. In rural Central Appalachia, a legacy of coal mining has removed some of the natural protections that could help alleviate flooding risk (Kenning et al. 2022). The long history of extractive industries has resulted in the removal of trees, topsoil, and rocks, contributing to erosion (Kenning et al. 2022) and creating flat coal chutes, which are conducive to rainwater running off and flooding lower ground (Hagan 2023).

In July 2022, some communities in eastern Kentucky received 14-16 inches of rain in a five day period - with some receiving over eight inches in a 24-hour period - causing extreme, historic flooding in 13 counties; in addition, observed rainfall totals across eastern Kentucky were over 600% of normal (National Weather Service 2022). This 1-in-1,000 year event caused widespread destruction and disruption to rural water systems, which hampered the availability of water and sanitation access. At least three wastewater plants were rendered completely inoperable, and several others had limited operations from infrastructure damage caused by flooding, mudslides, and rockslides, as well as power outages. The flooding necessitated hundreds of helicopter and boat rescues and swept away entire homes and even portions of some communities, leading to dozens of deaths and costly infrastructure damage (National Weather Service 2022). An estimated 18,000 service connections lost access to water, and another 45,600 connections received boil notices (American Water Works Association 2022). The Federal Emergency Management Agency (FEMA) provided $108.8 million in disaster aid to 8,747 individuals and households and $81.5 million for public agency assistance (Federal Emergency Management Agency 2023).

In the Western United States, water management is increasingly confronted with rain-on-snow (ROS) events. In a typical winter season, snowpack accumulates in mountainous regions, serving as a natural reservoir that slowly releases water during the spring and summer months as the snow melts. However, if rain falls on snowpack (i.e., ROS), it can cause rapid snowmelt, producing flood events that are difficult to forecast (Hatchett and McEvoy 2017). These events make water more unpredictable in time and place (Musselman et al. 2018). As an example, a large, warm atmospheric river[13] in February 2017 over the Sierra Nevada led to the Oroville Dam crisis in California (Musselman et al. 2018). During this ROS and subsequent flood event, dam operators opened Oroville Dam's spillway, which eroded and failed, leading to emergency evacuations of over 188,000 people downstream (Stork et al. 2017). Socioeconomic impacts of the disaster lingered long after the evacuation, which included financial losses (e.g., lost productivity and wages), emotional impacts (stress and trauma of the evacuation), and economic losses from loss of recreational opportunities in the area, among others (Stork et al. 2017). Work by Musselman et al. (2018) indicates that while ROS events will become less frequent at lower elevations due to snowpack decline, it may become more frequent in places like the Sierra Nevada and the Colorado River headwaters, increasing flood risk by 20–200%. The Fifth National Climate Assessment notes that even in places that are experiencing an overall drying trend, "atmospheric rivers are expected to become stronger and wider, increasing the risk of downpours and floods across the western United States" (Marvel et al. 2023). Furthermore,

---

[13] Atmospheric rivers are concentrated columns of water vapor, critical to the global water cycle for moving water vapor from tropical regions to other regions, but that often cause extreme precipitation events resulting in severe flooding; atmospheric rivers contribute roughly 22% of total global runoff (Paltan et al. 2017).

atmospheric rivers have become warmer along the Pacific coast over the past several decades, transporting larger amounts of moisture further into the Western United States (Chang et al. 2023).

Flooding and heavy rainfall increase erosion and destabilize landscapes. Research on the impacts of climate change to landslide events indicates that in places where rainfall events become more frequent and severe, there may be increased risk of landslides (Gariano and Guzzetti 2016). When slopes fail, sediment and debris can flow into, disturb, and contaminate water sources, such as rivers, lakes, and reservoirs (Smith et al. 2011; Göransson et al. 2018). While flooding and landslides are natural processes, disturbances to landscapes, such as from wildfire (discussed in Section 4.6 below), logging, mining, or other extractive activities can contribute to increased flooding and landslides and increase the amount of contaminants being transported into waterways (Smith et al. 2011; Bruggers 2019). After a wildfire in the Colorado Front Range, flash floods caused by heavy summer rainfall led to high amounts of erosion and sediment flowing downstream and into a reservoir (Moody and Martin 2001; 2004). These events contribute to water quality degradation, making delivery of safe water a challenge.

Even when flooding and extreme rain do not cause landslides and erosion, oversaturated roads can create challenges for providing water to remote communities. On parts of the Navajo Nation, where dirt roads become impassable after a large amount of rainfall, people who are dependent on hauled water can be left without access to any drinking water and storms (DigDeep 2022). Climate models project an increase in heavy downpours in the Southwest, so this could become a more recurring issue (Gonzalez et al. 2018; White et al. 2023).

As climates change, water and wastewater systems will need to make costly upgrades to help protect drinking water and sanitation access. The most recent survey and assessment by the US EPA of drinking water infrastructure found that over the next 20 years there is a need of $625 billion to ensure water systems continue to provide safe drinking water to the public (US EPA 2023d).[14] The summary shows that the largest proportion of this need is for distribution and transmission infrastructure with a total estimated need of $420.8 billion; the other areas of need include for treatment ($106.4 billion), storage ($55.3 billion), source water itself ($24.9 billion), and other projects ($17.6 billion). This survey also estimated that Tribal drinking water infrastructure needs more than $4 billion over the next 20 years. A similar analysis of the capital investment needs related to wastewater infrastructure was published by the US EPA in 2012. While now out of date, at that time the total need for meeting the water-quality goals of the Clean Water Act and goals related to public health were $271 billion (US EPA 2023a). This need was spread across various levels of wastewater-treatment processes, conveyance repair and construction, combined sewer overflow corrections, stormwater management, and recycled water distribution. An updated estimate for national wastewater treatment needs is expected in 2024. These numbers are based on surveys of capital investment needs deemed necessary by water and wastewater utilities, which may or may not be working to incorporate climate change projections into their capital plans. Ensuring that investments made to address these needs can withstand expected climate changes will require infrastructure design and operational guidelines that account for future climate scenarios and related emerging risks (Wasley et al. 2020).

---

[14] The US EPA's Drinking Water Needs Survey and Assessment is performed every four years and only considers infrastructure improvements that are eligible under the Drinking Water State Revolving Fund (DWSRF). DWSRF includes projects that are necessary for water systems to continue to provide safe drinking water to the public.

4.3.1 Inland Flooding and Decentralized Drinking Water and Sanitation Systems

Inland flooding poses a risk to decentralized water systems.[15] Approximately 42.5 million Americans rely on unregulated private wells for their drinking water (Gibson et al. 2020). Private wells that rely on shallow groundwater with more direct connection to surface water bodies may be vulnerable to contamination and affected by seasonal variation in precipitation. For example, in the *colonias* and other unincorporated communities in the Southwestern United States, research demonstrated that well water quality depended on the amount of rainfall seasonally with respect to arsenic and bacterial contamination (e.g., *Escherichia coli*), which leaves populations served by domestic wells vulnerable to health risks during both wet and dry periods (Rowles III et al. 2020). Flooding creates additional risk of contamination, determined in part by what type of land use is affected by the floods. Floodwaters carry pollution from all surfaces into local waterways. Fertilizers can come from agricultural and residential areas, pathogens, bacteria, and chemicals can come from industrial and urbanized areas, and heavy metals from roadways and mining sites.

There is also research beginning to link climate change and the contamination of groundwater and surface water from per- and polyfluoroalkyl substance (PFAS) compounds and microplastics, both more recently recognized classes of chemicals that can leach during rain and flooding events from landfills, agricultural lands (pesticides use microplastics as fillers), biosolids from wastewater treatment plants, and even septic systems (Gander 2022).[16] Gander states there is growing evidence that increased flooding from climate change and more intense storms increases deposition of pollutants (like PFAS and microplastics) on low-lying urban areas and floodplains.

Contamination of drinking water sources by floodwaters can render them unsafe for consumption without appropriate treatment, jeopardizing water access. Households are advised to have well water tested after flooding to ensure potability, and damaged systems require professional inspection and service for repairs and cleaning (US EPA 2015b).[17]

Despite the known risks of well water, private wells are not regulated by federal drinking water standards (i.e., the Safe Drinking Water Act; more on this and other federal water laws to come in future reports in this series). There is no national standard or requirement for testing private wells, nor do state governments typically require private wells to be tested (Flanagan and Zheng 2018). Additionally, there is limited information available or funding assistance to owners for well stewardship (Malecki et al. 2017; Mulhern et al. 2022; Sohns 2023). Well stewardship practices

---

15 Herein when we talk about decentralized systems, we are simply referring to those that are not connected to centralized systems that rely on a large water treatment facility and pumping station, or wastewater treatment plant to perform these same processes. Here decentralized systems primarily refer to private wells and onsite septic systems.

16 PFAS compounds and microplastics (plastics ranging in size from 1 to 5 mm/.04 to .2 in) may have toxic health impacts in humans and are found throughout the global water cycle (Gander 2022). Gander explains that PFAS compounds are used to make products resist heat and stains, repel water, and reduce friction. The same study says that PFAS are found in many household and industrial products such as non-stick pans, water-repellent clothing, stain-resistant furniture, and fire-fighting foam. Microplastics are the result of larger plastics breaking down into smaller pieces and are sourced from roadways, wastewater, and stormwater, among other places. Both sets of contaminants are resistant to degradation processes. As recently as June 2023, the US EPA has proposed a national drinking water standard that would require water utilities to remove six types of PFAS compounds from drinking water (US EPA Office of Water 2021). To date, there is only one federal act regulating microplastics, the Microbead-Free Waters Act of 2015 (US Food and Drug Administration 2022).

17 See more on related disaster preparedness and water well flood response steps here: https://www.epa.gov/privatewells/protect-your-homes-water.

including testing have been found to be minimal (Colley et al. 2019). For example, only about half of surveyed private well users in Wisconsin have had their well water tested within the last 10 years, and of those, only 10% had tested their water in the last 12 months (Malecki et al. 2017). If tested water is found to be contaminated, filtration systems or bottled water sources can be burdensome or too costly for low-income households (Sohns 2023).

Due to these constraints, people who rely on private well water face higher risks of waterborne contaminant exposure than those who are served by regulated community and municipal water systems (MacDonald et al. 2017). Furthermore, recent research has shown that low-income, marginalized and minority communities disproportionately experience a lack of access to water services, have a higher dependence on private wells, and have increased exposure to water pollutants (Sohns 2023).

In addition to private wells, decentralized sanitation systems, such as septic tanks, may be damaged by climate change with increased flood risk through siltation and debris and oversaturation of leach fields (Calabretta et al. 2022). If a septic tank is in a saturated condition, there is a risk it will not allow sewage to flow properly, potentially leading to sewage backups into the home or contamination of groundwater supplies (Calabretta et al. 2022). A report conducted by Miami-Dade County predicts that the number of residential sanitation systems that may be “periodically compromised” during storm events or particularly wet years will increase by 8% between 2018 and 2040 (Miami-Dade County and Florida Department of Health 2018). In Nueces County, Texas, researchers found households in *colonias* that use domestic wells and septic and cesspool systems experience higher bacterial contamination of their drinking water during wetter periods (Rowles III et al. 2020). The research team also found higher levels of arsenic during dry periods, and through a nationwide analysis of unincorporated communities, they think this seasonal water contamination challenge related to flooding and drier times may be occurring elsewhere.

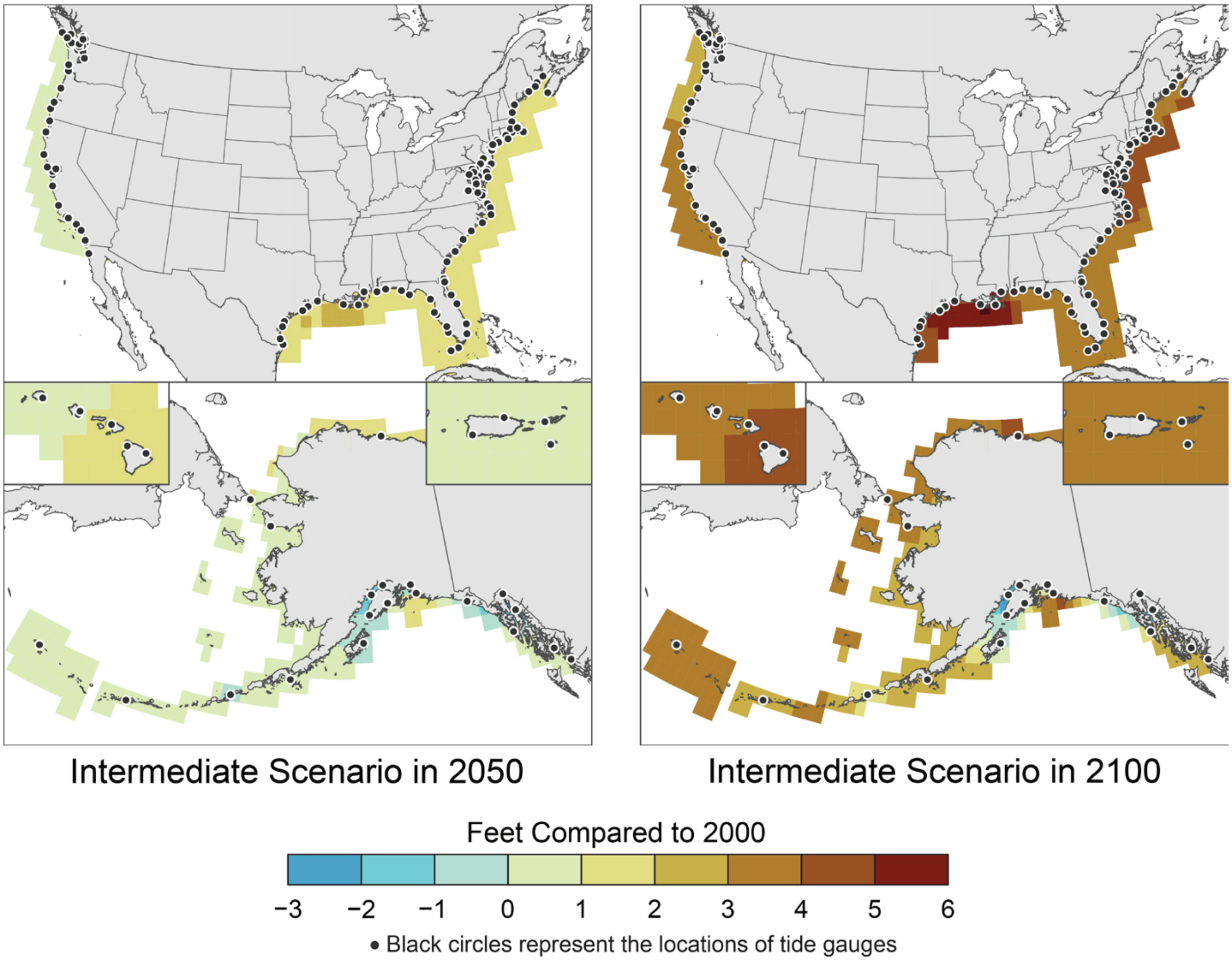
While rural households are most likely to rely on these types of onsite wastewater systems, they can also occur in urban or exurban areas and are most likely to be in households at or below the median income level (Calabretta et al. 2022). Calabretta et al. infer that the use of decentralized wastewater systems may correlate with racial or ethnic household makeup, but data are nonexistent or sparse due, in part, to how the US Census changed data collection on plumbing access in the early 2000s. Given the correlation of race to related issues like poverty, water insecurity, disaster recovery, and climate vulnerability (Meehan et al. 2020; Howell and Elliott 2019; Thomas et al. 2018), we would expect the same is likely true for sanitation.

4.4 SEA LEVEL RISE

Sea level rise is the process by which the average height of the sea rises above its historical average. This process is driven by two factors related to climate change: thermal expansion, which is the expansion of ocean water as its temperature rises, and melting of land ice, such as glaciers and ice sheets (US Global Change Research Program n.d.). Global mean sea level has risen 17 cm (6.7 inches) in 100 years (1920–2020), with an acceleration in the rate of rise since 1970 (Sweet et al. 2022). Along coastlines around the contiguous United States, sea level rise has averaged 28 cm (11 inches) over that same period (Sweet et al. 2022). Over the next 80 years, sea level along contiguous US coastlines is projected to rise 0.6 m (1.9 ft) to 2.6 m (8.5 ft) over a range of emissions scenarios

(Sweet et al. 2022). Figure 12 shows projected relative sea level change for 2050 and 2100 for all US coastlines under an intermediate emissions scenario (May et al. 2023). The rising of seas is not uniform and varies based on a number of factors, such as coastline geology, tides, and winds (US Global Change Research Program n.d.). Reductions in sea level in some regions, such as parts of Alaska, are due to rapid tectonic uplift (Johnson et al. 2019).

FIGURE 12. Projected Relative Sea Level Rise (in Feet Compared to 2000) for United States Coastlines through 2050 and 2100, Intermediate Emissions



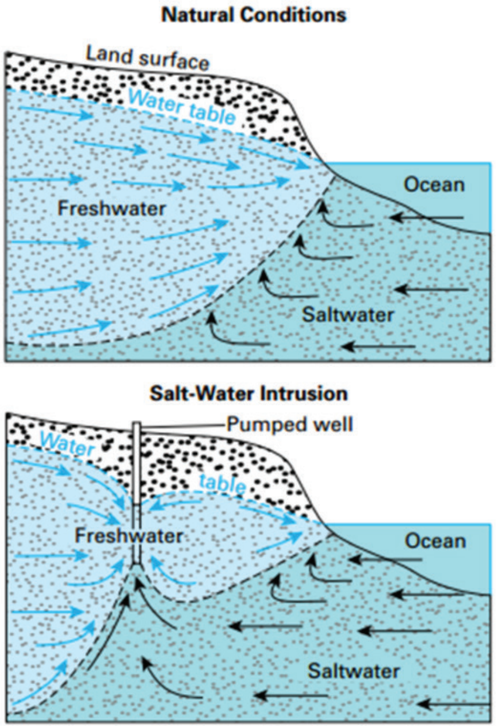
Note: The left panel shows projected relative sea level rise by 2050 and the right panel shows projected relative sea level rise by 2100, both under an intermediate (RCP4.5) emissions scenario.

Source: May et al. 2023

4.4.1 Sea Level Rise Impacts to Water Quality

Sea level rise can affect drinking water quality, contribute to flooding, and damage water and sanitation infrastructure through elevated high tides and storm surges. Water-quality impacts of sea level rise are primarily caused by saltwater intrusion, the process by which saline water moves into freshwater aquifers (USGS 2019). Saltwater intrusion can occur due to higher baseline sea levels from climate change, storm surge, or when high tides flood low-lying areas, causing infiltration of saltwater into freshwater aquifers (USGS 2019). Even without climate change, saltwater intrusion into coastal aquifers can be caused by over-pumping of groundwater, which allows saltwater to migrate landward (Figure 13). This saltwater intrusion can adversely affect coastal communities' access to drinking water by rendering water supplies brackish or saline, making them unfit for drinking, cooking, and irrigation without expensive, energy-intensive treatment.

FIGURE 13. **Example of Saltwater Intrusion from a Pumped Well**



Source: USGS 2019

The movement of salt water up rivers and other waterways during droughts or other periods of low freshwater levels is another phenomenon more likely to occur with rising sea levels. This can affect water quality, inhibiting the effectiveness of drinking water treatment systems, causing at least temporary backsliding in access for their communities. Low flows in the Mississippi River Delta, such as occurred in the summer of 2022 and again in 2023, allows saltwater to move tens of miles upstream, where it can contaminate water supplies for municipal and industrial water users for weeks to months (Yuill et al. 2023; Lynch and Ramirez 2023). The US Army Corps of Engineers (USACE) documented saltwater intrusion (called a "saltwater wedge") extending 62 miles inland during a low-flow year on the Mississippi River in 2022 (Yuill et al. 2023). During this event, Plaquemines Parish's water supplies were contaminated, forcing the local authorities to issue an emergency declaration to help instigate response measures such as supplies of bottled water for parish residents (Plaquemines Parish Government 2022). To mitigate saltwater intrusion impacts to Plaquemines Parish and other upstream communities, the USACE constructed an underwater sill to restrict the movement of saltwater further upriver (USACE 2022).[18] Then again in 2023, the saltwater wedge returned due to low flows from drought throughout the Mississippi River Basin, causing the USACE to add 25 feet of height to the underwater sill (Lynch and Ramirez 2023). The USACE was also barging 36 million gallons of fresh water a day to local water treatment plants in the New Orleans area that have water intakes impacted by the intrusion of salt water (Lynch and Ramirez 2023).

4.4.2 Sea Level Rise Impacts to Water and Sanitation Infrastructure

Changes in average sea level have doubled the frequency of disruptive high tide flooding in the continental United States over the past few decades (Marvel et al. 2023). Sea level rise can also threaten coastal water infrastructure, such as wells, pumping stations, and treatment facilities, with inundation from coastal flooding and storm surges. Water supplies and wastewater infrastructure in coastal Alaska have been damaged by saltwater intrusion and storm surge (Penn et al. 2016; Markon et al. 2018). As recently as mid-September 2022, coastal Alaska was dealing with life-altering flooding from historic storm surge in frontline communities already dealing with the impacts of coastal erosion (Rosenthal and Feuerstein 2022). Many people lost their homes, and communities suffered from prolonged high-water conditions (Rosenthal and Feuerstein 2022). Changes in average sea level have doubled the frequency of disruptive high tide flooding in the continental United States over the past several decades (Sweet et al. 2018).

As seas rise, causing nuisance flooding and in some cases complete inundation, low-lying infrastructure such as wastewater treatment plants can be damaged or destroyed. In 2012 the Pacific Institute found that along the San Francisco Bay a 1.0-meter (3.28 feet) rise in sea level would put eight wastewater treatment plants at risk of a 100-year flood event, and 10 at risk with 1.4 meters (~4.6 feet) of rise (Heberger et al. 2012). Research shows that sea level rise due to climate change will corrode and degrade concrete infrastructure, causing its useful service life to decrease (Gao and Wang 2017). This can increase maintenance costs, reduce efficiency, and require expensive repairs or replacements. Impacts and disruptions to wastewater services from infrastructure damage are felt by entire communities, not just those who live on the coastline. An assessment of the exposure of wastewater infrastructure to various sea level rise projections across the country found that as many as five times as many people will be impacted by wastewater system exposure to sea level rise than due to direct flooding of residences (Hummel et al. 2018). This study also found that flooding of wastewater treatment facilities from sea level rise will occur both from overland inundation as well as from rising groundwater tables (where coastal aquifers are present). Of note, the research did not account for the joint impacts of sea level rise and storm surge, which can increase the amount of damage from overland inundation when combined in coastal environments, as discussed in the next section.

---

[18] Yuill et al. (2023) state that saltwater intrusion is common in many low-slope, coastal rivers worldwide, but the USACE's active river channel dredging to maintain river depths below natural bed levels for shipping contributes to saltwater intrusion on the Mississippi River; low flow years exacerbate this challenge.

4.5 EXTREME STORMS

Extreme storms are extreme weather events that are often short-lived and occur infrequently at a certain place and time (Kossin et al. 2017; Seneviratne et al. 2021). Extreme storms include a range of event types; here we focus on tropical cyclones (hurricanes), severe convective storms (especially in the form of tornadoes), and severe coastal winter storms, and how these events are changing and challenging water and sanitation access for frontline communities.[19]

4.5.1 Hurricanes and Tornadoes

Hurricanes are a type of tropical storm event characterized by sustained winds of 74 miles per hour (mph) or higher (NOAA 2023a). Hurricanes that affect the United States typically occur in the North Atlantic Ocean, but in 2023 (when this report was written) a hurricane in the Pacific approached the southern Pacific coastline of the United States, which led the National Hurricane Center to issue its first-ever tropical storm warning for parts of southern California (Thiem 2023). Hurricane Hillary did not make landfall in the United States, but it did in the northern Baja Peninsula in Mexico as a tropical storm (Thiem 2023). Still, as a tropical storm, it caused severe flooding and power outages due to downed trees across several communities in southern California and one person dead in Mexico (Olson and Treisman 2023). An assessment of the latest generation of climate models shows an increase in both the intensity and frequency of tropical cyclones as greenhouse gas emissions rise (Emanuel 2021) (See Figure 14 for hurricane paths between 1900 and 2021). They are also becoming more intense more quickly, leaving people with less time to prepare by purchasing bottled water and other emergency supplies (Bhatia et al. 2019; Marvel et al. 2023).

> In coastal communities with steep terrain, hurricanes can lead to landslide activity that knocks out power or causes damage to water and wastewater infrastructure.

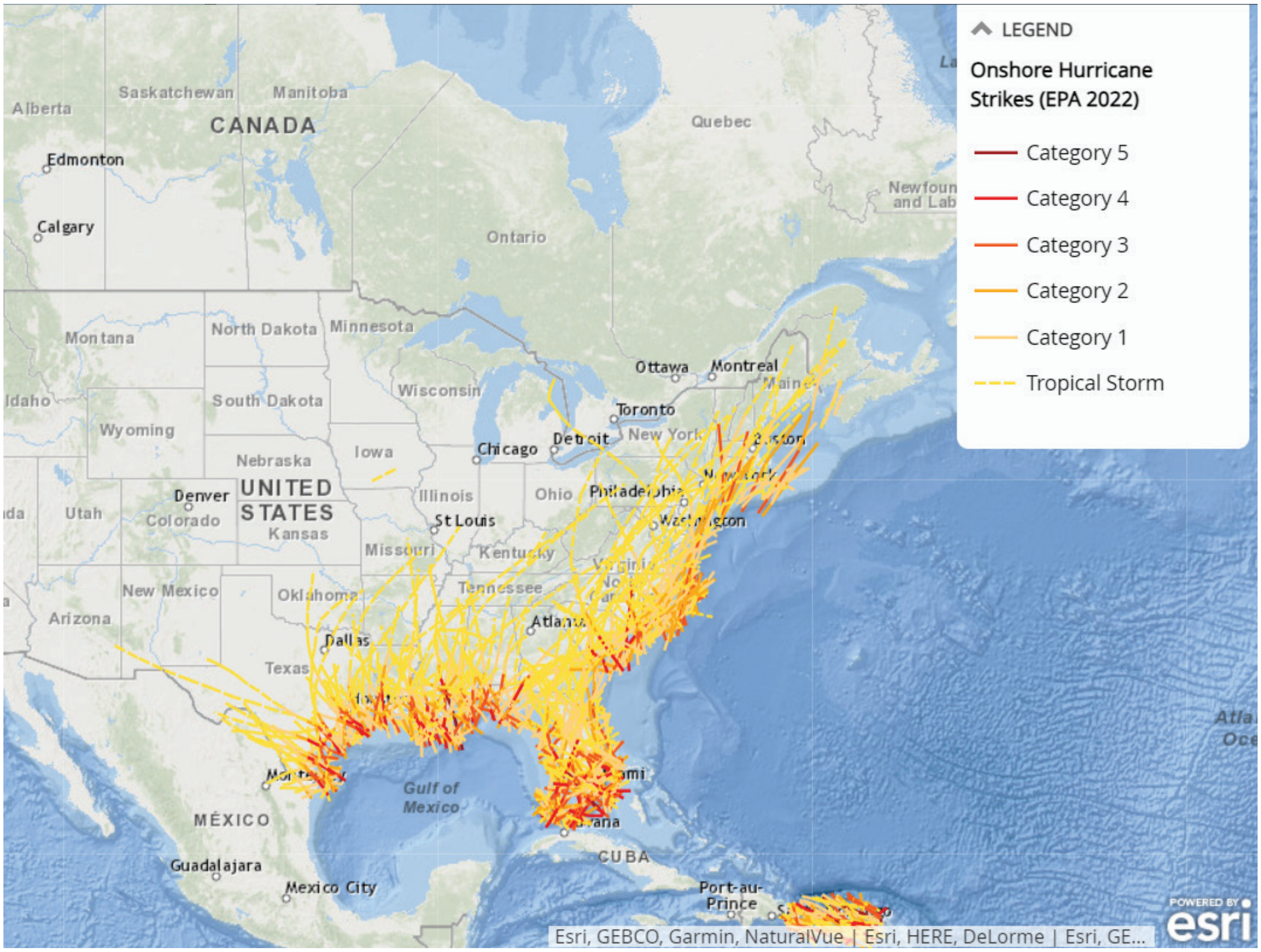
Hurricanes in the North Atlantic have also been moving slower, dropping more rain, and causing more flooding and wind damage once they make landfall (Marvel et al. 2023). High winds are a major cause of damage to human structures and vegetation during hurricanes, but hurricanes also contribute to flooding of coastal regions through a combination of heavy precipitation, waves, and storm surge. During Hurricane Harvey (2017) extreme precipitation was 15–20% heavier with 33–80% worse flood damage than it would have been without human-caused climate change, and it killed 100 people and cost $147.6 billion (Payton et al., 2023; Wehner and Sampson 2021; Smiley et al. 2022). Black, Hispanic, disabled, and low-income communities suffered the worst in myriad ways through chemical exposures (Flores et al. 2021), living in areas not covered by federal flood insurance (Billings et al. 2022; Payton et al., 2023), or not being able to prepare or respond because of disabilities or financial constraints, among others (Chakraborty et al. 2019; Billings et al. 2022).

---

[19] Winter storms and atmospheric rivers can also be categorized as extreme storms and are touched on in the Extreme Temperatures and Inland Flooding sections, respectively.

As discussed in Section 4.3 above, flooding can cause loss of access to water and sanitation by damaging infrastructure and contaminating water supplies. In coastal communities with steep terrain, hurricanes can lead to landslide activity that knocks out power or causes damage to water and wastewater infrastructure. Hurricane Maria in 2017 caused an estimated 40,000 landslides in Puerto Rico, leaving much of the island without power (Bessette-Kirton et al. 2019). Loss of power may also lead to loss of functionality of both centralized and decentralized water and sanitation systems, leaving those in impacted areas without water or sanitation access. Research is ongoing to understand how the impacts of climate change, such as sea level rise and changes in extreme wave height, interact with hurricane events and how they may contribute to increased risk and reach of flooding of coasts and coastal communities (Seneviratne et al. 2021).

FIGURE 14. Hurricane Systems 1990–2021



Note: Each of these storm systems reached hurricane strength as the storm center was within 50 nautical miles of the US coastline. The strength, measured by hurricane category, is represented with colors from yellow (Category 1) to red (Category 5); tropical storm segments of these hurricanes are shown as dotted lines.

Source: US EPA 2021a

Climate change will not only intensify extreme storms but also change storm patterns and increase strength and frequency of tornado outbreaks (Marvel et al. 2023). Thunderstorms, which can cause hail and lightning strikes that also knock out power and leave other damage, are likely to occur at less common times of the year, spring and fall, especially under higher warming scenarios (Marvel et al. 2023). Recent research has also found a significant east, southeast, and potentially northeast geographic shift in tornado activity due to rising global temperatures (Cao et al. 2021; Krainz and Hu 2022). This shifts tornado activity from the Great Plains region (including Texas, Oklahoma, Kansas, Nebraska, and Iowa) to Missouri, Arkansas, Louisiana, Mississippi, Alabama, and Tennessee. Other research has shown that between 1979 and 2017 there was a downward trend in tornado activity in Texas and Oklahoma, while at the same time there was an increasing trend in tornado activity to the east in Arkansas, Louisiana, Mississippi, and western Alabama and Tennessee (Gensini and Brooks 2018). Hurricanes have also been shifting poleward in both hemispheres (Seneviratne et al. 2021).

As extreme storms increase in intensity and frequency and shift to new geographic locations, substantial damage can occur to water and wastewater infrastructure and disrupt water and sanitation access. High winds, heavy rainfall, and storm surges that knock out power and cause flooding, landslides, and severe erosion can lead to the destruction or disruption of water and wastewater treatment systems (Lall et al. 2018). Infrastructure damage from these extreme storms can result in water-supply interruptions and compromised water quality, affecting drinking-water access for communities. During Hurricanes Katrina and Rita in 2005, there were systematic breakdowns of centralized water and wastewater infrastructure. A 2006 report by the Congressional Research Service found that damage to drinking water and wastewater facilities in the Gulf Coast region from Hurricanes Katrina and Rita included flooding, structural damage to water delivery and treatment systems, and the loss of electrical power to pump, process, and treat water and wastewater (Congressional Research Service 2006). Water and wastewater treatment plants and pumping stations require electricity to operate, and when power is lost treatment capacity can be reduced or completely stopped. In 2006 in the Gulf Coast, restoration of drinking water and wastewater services took weeks to months (Congressional Research Service 2006). Restoring service was challenged by factors including clogged engines, pumps, and lift stations; waterlogged electrical systems; contamination by toxic chemicals and harmful bacteria; difficulty restoring pressure to water distribution systems; disinfection efforts; cleaning and repairing pipes; and repairing and rebuilding infrastructure (Congressional Research Service 2006). These hurricanes, which left many homes without access to water and sanitation for days to months, provide another example of how an extreme weather event can result in water access backsliding.

> High winds, heavy rainfall, and storm surges that knock out power and cause flooding, landslides, and severe erosion can lead to the destruction or disruption of water and wastewater treatment systems.

Tornadoes, which can be accompanied by floods, hail, and lightning, can also cause severe local impacts and damage to water and wastewater infrastructure, causing loss of water and sanitation access (US EPA 2015c). The EPA, in an Incident Action Checklist for water and wastewater utilities preparing for and responding to tornadoes, lists damage to infrastructure such as storage tanks, hydrants, and residential plumbing fixtures, due to hail, wind, debris, and flash flooding as the main impacts from these storms (US EPA 2015c). Damage may result in total loss of service and/or reduced pressure throughout the system. In December of 2021, several tornadoes caused damage to homes, businesses, and water and wastewater infrastructure in western Tennessee and eastern Kentucky (Godwin 2022). This extreme storm featured multiple EF-4 tornadoes (wind speeds up to 200 mph) and peaked at a "high end" EF-4 (Schreiner and Galofaro 2021). The path of the storm system was approximately 250 miles long, and 83 people died as a direct result of the event. Several days after the event, 10,000 structures had no water at all, and an additional 17,000 were placed under boil-water advisories (Schreiner and Galofaro 2021). Many small rural water and wastewater utilities in the area were without power and had to obtain generators to get back online; they also experienced major water loss through damage to both above-ground and below-ground pipes and infrastructure (Godwin 2022). Mayor Kathy Stewart O'Nan of Mayfield, Kentucky reported, "Our infrastructure is so damaged. We have no running water. Our water tower was lost. Our wastewater management was lost, and there's no natural gas to the city. So, we have nothing to rely on there. So that is purely survival at this point for so many of our people." (Associated Press 2021). Even three months following the event, some of the water and wastewater systems were still dependent on emergency generators to operate (Godwin 2022).

4.5.2 SEVERE COASTAL WINTER STORMS

In coastal Alaska, extreme weather events along the coast in the fall and winter since at least the early 2000s have left many communities exposed to coastal storm waves that damage water and sanitation infrastructure, increasing risk of exposure to water-related infectious disease (Markon et al. 2018; Thomas et al. 2013). Climate change has caused a reduction in sea ice cover and a rise in sea level, making these severe winter storms even more impactful on the coastal environment (Markon et al. 2018). A 2016 survey of residents and professionals from Arctic nations found that respondents from Alaska have experience or knowledge of damage to water and sanitation infrastructure, including from overland flow during intense storms, as well as increases or changes to operations and maintenance for water and sanitation systems from climate-caused changes (Bressler and Hennessy 2018). National survey data from 2017–2021 indicates 2.5% of American Indian and Alaska Native households lack complete plumbing (compared to 0.4% of the total population) (US Census Bureau 2021), and research from Alaska suggests that this gap in basic access is only increasing (Brown et al. 2022).

As climate change makes extreme storms more frequent, there are important social impacts and inequalities to consider related to water and sanitation access.

4.5.3 Inequitable Social and Health Impacts of Extreme Storms

As climate change makes extreme storms more frequent, there are important social impacts and inequalities to consider related to water and sanitation access. Howell and Elliott (2019) analyzed changes in wealth inequality before and after natural disasters at the county scale. They found that wealth inequality worsens in counties with more disasters. Furthermore, they found that the growth in wealth inequality after a natural disaster is more pronounced by race and lower levels of education and homeownership. They also showed that wealth inequality grows by the largest proportion, especially for people of color, in counties where FEMA aid was provided post-disaster. Property owners and those with greater financial resources are able to apply for support, including deferral recovery investments in businesses, low interest loans, "significant" payouts from public and private insurance policies (including but not limited to the National Flood Insurance Program under FEMA), and intergenerational wealth transfer resulting from financial windfalls or property restoration and investment (Gotham 2014; Howell and Elliott 2019; UN Educational, Scientific, and Cultural Organization and UN-Water 2020). By contrast, non-property owners and those with fewer financial resources experience ripple effects from the increased likelihood of losing their jobs following a disaster, including having to move, paying higher rents due to reduced housing stock, and using up any existing savings to compensate for post-disaster expenses (Howell and Elliott 2019).

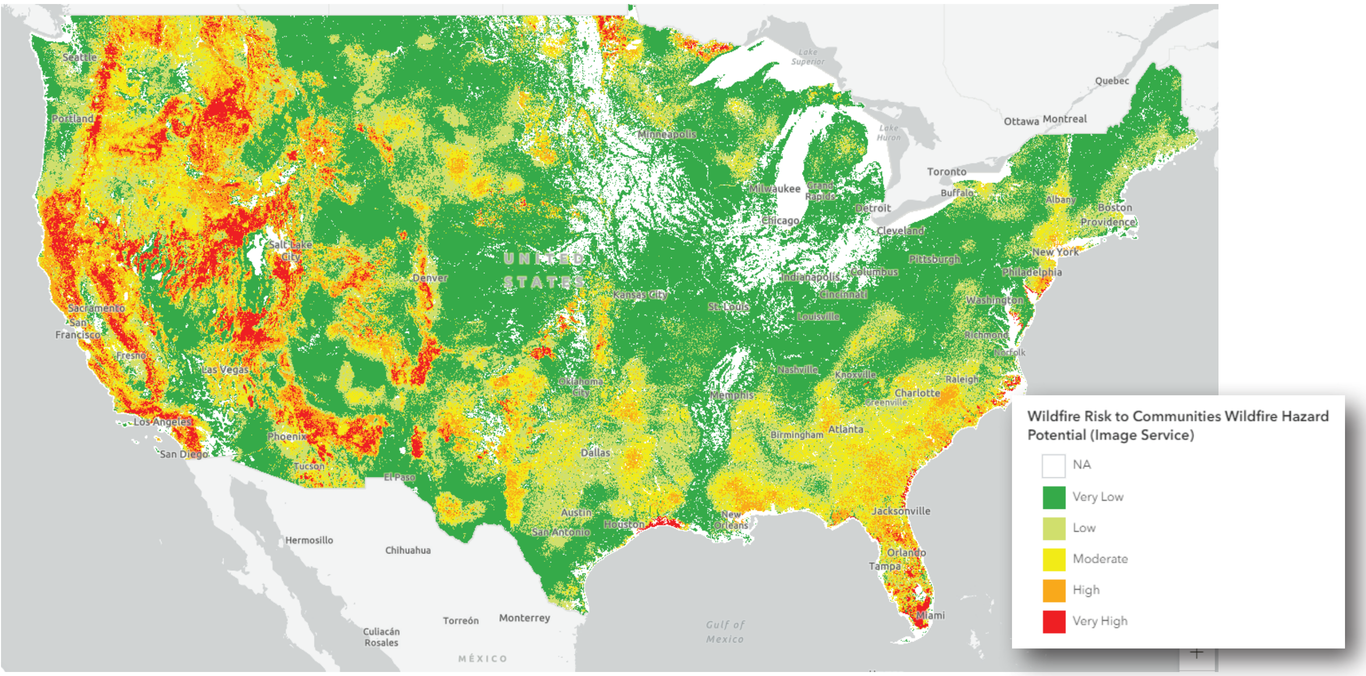
Widespread flooding from extreme storms has been associated with increased risk of exposure to bacterial and inorganic contaminants in water. In Portland, Oregon, an outbreak of *Shigella* (an infectious bacterial disease that causes gastroenteritis) occurred from July 2015 to June 2016, with noticeable transmission in the homeless population that coincided with the onset of the wettest rainy season on record (Hines et al. 2018). The researchers concluded that heavy precipitation likely contributed to this outbreak. After Hurricane Ian in 2022, several Florida residents died from illness related to the bacterium, *Vibrio vulnificus (V. vulnificus)* (also known colloquially as "flesh-eating bacteria") (Conrad and Harwood 2022). In a post-disaster setting, people may have been exposed to *V. vulnificus* via open cuts or sores as they waded through flood waters, or by consuming food or water that had been contaminated (Conrad and Harwood 2022). In 2017, Hurricane Maria reportedly cut water service to approximately half of the population of Puerto Rico, and a month later, one million people still lacked water access (Bacon 2017; Wang et al. 2022). Researchers studying the risk of adverse birth outcomes in mothers due to exposure to phthalates in Puerto Rico at the time measured increased markers of these toxic chemicals from food packaging post-hurricane in their study population (Watkins et al. 2020). Study participants also indicated that, post-hurricane, they had been without running water or access to fresh foods.

4.6 WILDFIRES

In a global review of the state of wildfire and bushfire science, Haghani et al. (2022) define a wildfire as "unplanned and unwanted burnings of combustible vegetation often occurring in rural areas." Wildfires that burn houses and communities present a direct threat to water infrastructure during the fire and can place high demand on limited water resources to subdue and extinguish flames. After a wildfire occurs, surface water supplies in the impacted watershed and water within damaged distribution systems can be contaminated and unsafe to drink. The potential for wildfires is increasing in frequency, geographic and temporal extent, and severity (Vose et al. 2018; US EPA 2022) as a result of earlier snowmelt, increased temperatures, larger vapor pressure deficits, increased wind speeds, decreases in precipitation, and increased tree mortality in forests (which itself has been linked to extreme heat and drought) (Vose et al. 2018; Holden et al. 2018; Domke et al. 2023). The Fifth National Climate Assessment shows that from 1984 to 2015, about half of the increase in burned area across the Western United States is attributable to increases in fuel flammability caused by anthropogenic climate change (Leung et al. 2023). Zhuang et al. found that human-caused warming in the period 1979–2020 was responsible for almost 68% of the observed drying of landscapes, making wildfires burn larger areas (2021). Research has also shown that, at least in California, wet winters no longer correspond with reduced wildfire risk. The scientific community and wildfire managers are seeing a trend where extreme precipitation that causes high growth of vegetation will, in turn, increase the risk of wildfires as conditions dry (Wahl et al. 2019; Bellisle 2022), for example, when a very wet spring and summer turn to a dry fall and winter. These were the conditions, combined with strong winds, that played a role in the devastating Marshall Fire in Colorado in December 2021. In the United States, decades of fire suppression activities have allowed fuel accumulation, also contributing to higher intensity wildfires, especially in the West (Keane et al. 2002).

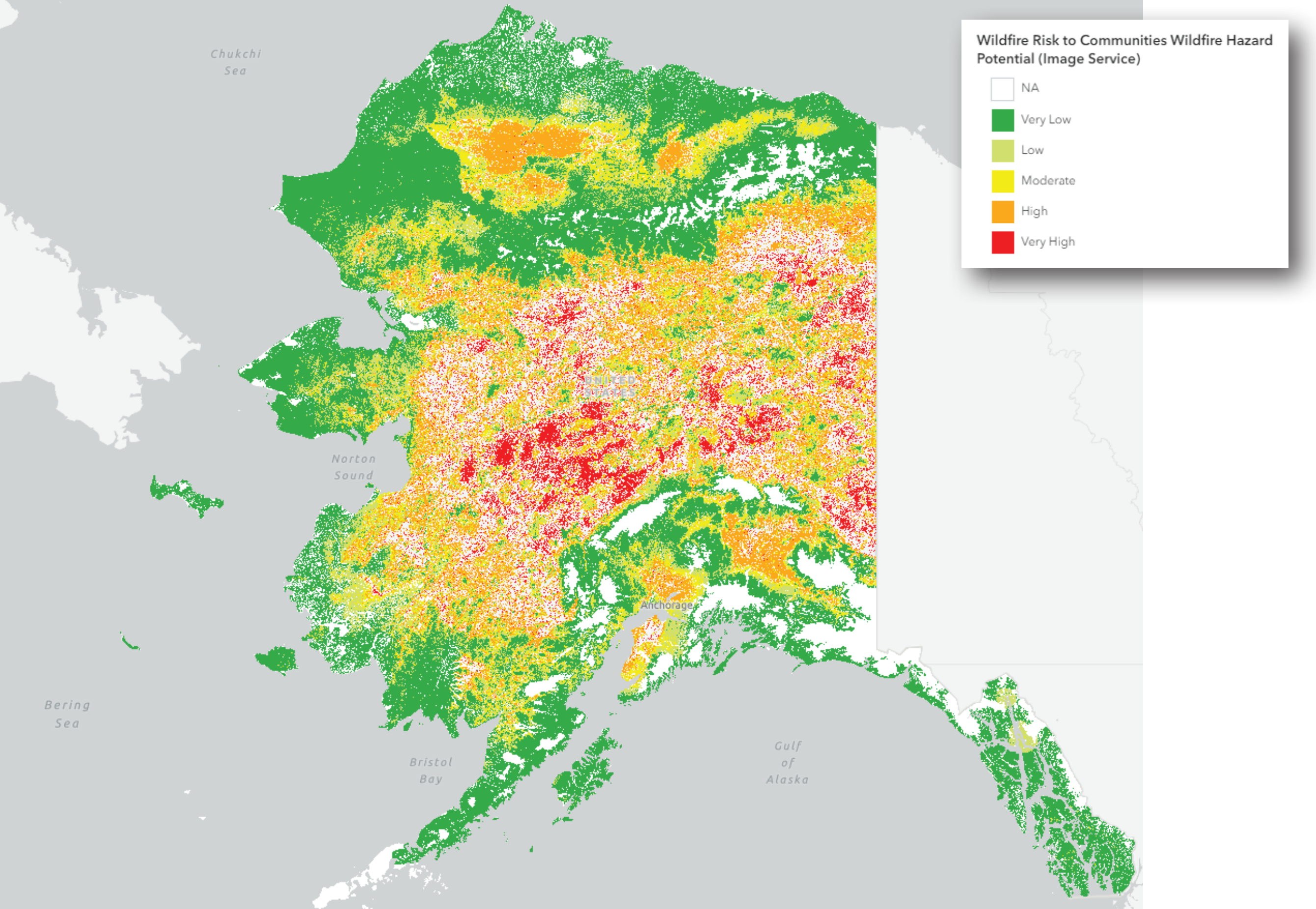
California, Arizona, and Nevada remain the most at risk for wildfires, but communities across the Southwest, Northwest, Midwest, Intermountain West, Alaska, and the Southeast also have high risk (Figures 15 and 16) (US EPA 2022). Many of the most at-risk homes and communities exist along what is called the wildland-urban interface, the zone where human development ends and transitions into wildland (Burke et al. 2021). More than 50 million homes in the United States currently exist in the wildland-urban interface, and this number is predicted to grow at a rate of approximately one million houses every three years (Burke et al. 2021).

FIGURE 15. **Wildfire Risk to Communities in the Contiguous United States**



Source: US EPA 2022

FIGURE 16. **Wildfire Risk to Communities in Alaska**



Source: US EPA 2022

4.6.1 Wildfire Impacts on Water Infrastructure

Wildfires that burn in and around communities can damage and destroy water infrastructure, causing immediate and longer-term loss of water access. A well-documented case of these impacts is provided by Proctor et al. (2020), who detail the water system and water quality impacts from the 2017 Tubbs Fire and 2018 Camp Fire in California. On the household scale, these fires melted and ruptured water pipes and water meters in homes (Proctor et al. 2020). These fires also burned, damaged, and destroyed private wells. The Camp Fire impacted an estimated 2,438 private wells (Proctor et al. 2020). In Oregon, roughly a quarter of residents rely on private wells (Oregon Health Authority n.d.). During the 2020 Labor Day Fire in western Oregon, more than 2,000 well-reliant households were exposed to heat and flames, resulting in well damage and destruction (Bolstad 2022).

On the community scale, wildfires can cause adverse effects to water intake systems and water treatment systems and reduce reservoir life span (Bladon et al. 2014). In the Camp Fire, the local water district had “many physically damaged assets” that delayed their ability to repressurize the system (Proctor et al. 2020). Those specifically noted included leaking fire hydrants, destroyed meter boxes, ruptured pipes, and plastic residue inside service lines (Proctor et al. 2020). Immediately following multiple severe fires in 2012 in Colorado, water managers installed monitors to help measure ash and sediment levels, worked to divert contaminated water from water intake points, and took preventative measures to reduce debris from the burned areas from entering water supplies (Bladon et al. 2014). For water treatment systems, operational changes may be necessary to address longer-term changes in the amount and type of solids and other constituents from impacted watersheds (Emelko et al. 2011). After a fire, landscapes commonly face increased erosion and landslides (i.e., debris flows) (Paul et al. 2022); reservoirs downstream of fire-impacted landscapes can act as the receiving body of these sediments (Moody and Martin 2004).

4.6.2 Wildfire Impacts on Water Quality

Wildfires can make drinking water unsafe for both the communities within the burn scar and for those downstream due to the contamination of water supplies with chemicals and sediment (H.G. Smith et al. 2011; Bladon et al. 2014). Waterways downstream of fire-impacted forested catchments see measurable increases in the concentration of solids, nutrients (which can lead to eutrophication), heavy metals, and temperature post-fire (Bladon et al. 2014). Sediments, which are a primary carrier of much of these contaminants, increase in volume downstream post-fire (H.G. Smith et al. 2011). Fires deposit layers of ash and remove vegetation as well as soil organic matter, leading to an increase in runoff and erosion in burned areas during rainfall and snowmelt periods (Moody and Martin 2001; 2004; Writer et al. 2014). After the High Park Fire in Colorado in 2012, storms washed ash and debris into the Cache la Poudre River, degrading Fort Collins's water supply and forcing the city and surrounding communities to seek out alternative water supplies (Writer et al. 2014). Increased cyanide contamination may be a risk immediately following fire, especially because there are few standard methods for removal of cyanide from drinking water (Barber et al. 2003; H.G. Smith et al. 2011). Fortunately, studies have shown that increases in cyanide concentrations in stream water are typically for only a short period of time following the fire (H.G. Smith et al. 2011).

> Wildfires can make drinking water unsafe for both the communities within the burn scar and for those downstream due to the contamination of water supplies with chemicals and sediment.

Additional treatment systems and processes to remediate the impacts of wildfire on water quality can be very costly. These rising costs can present affordability challenges for households, potentially creating a barrier to water access if a household can no longer afford their utility bill. In the rural, largely Hispanic town of Las Vegas, New Mexico for example, residents of the city could face costs estimated at $100 million to fix their water filtration system from a wildfire that burned a large swath of forest nearby in 2022 (Romero 2022). In this case, 32% of the population lives below the poverty line, and many may not be able to afford rising costs to replace their community's water-treatment system (Romero 2022). A review of economic analyses of wildfire impacts to water quality by Wibbenmeyer et al. (2023) found “no studies that have specifically estimated the costs of wildfires on water treatment,” but they cite several studies documenting an increase in water treatment costs in response to a decrease in water quality more broadly.

Drinking water supplies may be at risk for years to decades after a wildfire (Chow et al. 2019). Some of the more persistent water-quality challenges are associated with dissolved organic matter (Chow et al. 2019). Treating and disinfecting water contaminated with dissolved organic matter can result in the production of disinfection by-products (DBPs), which are carcinogenic and difficult to remove (Nieuwenhuijsen et al. 2009; Gilca et al. 2020). Trace elements may also persist in waterways post-fire, particularly during rainfall events that contribute to mobilization of impacted sediments (Burton et al. 2016). Seven years after the 2009 Station Fire in Angeles National Forest in California, researchers found iron, lead, nickel, and zinc to be persisting at concentrations harmful to aquatic life (Burton et al. 2016).

> Fires that burn into communities cause several direct impacts on drinking water quality at the household and community scale.

Fires that burn into communities cause several direct impacts on drinking water quality at the household and community scale. California’s 2017 Tubbs Fire and 2018 Camp Fire were the first known wildfires where widespread chemical contamination of drinking water was discovered in the water distribution network itself, rather than just the source water (Proctor et al. 2020). As a result of both fires, drinking water at homes and in the distribution system exceeded state and federal exposure limits for several volatile organic compounds (VOCs) including benzene (Proctor et al. 2020; Solomon et al. 2021), which was likely released from burned or damaged plastic pipes (Proctor et al. 2020; Meadows 2022). While in a fully pressurized, well-maintained distribution system it is unlikely that contamination in a service line (i.e., at a home or business) would lead to contamination of water in the main lines, a damaged system with pressure losses can push contamination from a service line to a main line (Solomon et al. 2021). Residents that rely on these water sources said that tap water and private domestic water had a smokey odor; in other cases, local water utilities deemed wildfire-impacted water sources unsuitable for use and had to supply alternative sources of water (Proctor et al. 2020; Chow et al. 2021).

Domestic wells can suffer many of the water-quality challenges experienced by centralized drinking water systems post-fire. Following the 2018 Camp Fire in California, the county advised testing of unregulated water sources and warned that contamination could also extend to the aquifers themselves, but a lack of direct support for testing made residents more reliant on expensive bottled water while the damage was assessed (Bolstad 2022). After the fires in Oregon in 2020, the state established a free voucher program to pay for testing of private wells for arsenic, nitrate, bacteria, lead, and, where warranted by a damage assessment, benzene, toluene, ethylbenzene, and xylenes (Oregon Health Authority 2023). This effort was built on the response of the Butte County Health Department (in California) after the 2018 Camp Fire. Following the Marshall Fire in Colorado in 2021, Jankowski et al. (2023) investigated fire damage on private domestic wells and well water. They visited 17 properties and were able to test water from 10 of the wells and sample from faucets, cisterns, and other parts of home water systems, where available. Debris was found in several samples and while no VOCs were detected, several samples contained semi-volatile organic compounds (SVOCs) at levels below federal drinking water safety limits. Other trace minerals were found at levels above EPA's health-based screening levels (lithium and vanadium), but it was unclear if the fires were directly related to these elevated levels.[20] One well visited had served eight homes, seven of which had burnt to the ground. Eleven months following the fire, this well was still inoperable, in part due to the high financial burden of restoring the system for the community. The wildfire that left these eight homes without access to water and sanitation for months offers another example of how an extreme event fueled by climate change can result in backsliding. Jankowski et al. concluded that their research highlighted the need for clear guidance and policy to support domestic well owners in dealing with the repercussions of wildfire on their water systems.

In August 2023, wildfires broke out on the Hawaiian Island of Maui, razing the town of Lahaina, killing close to 100 known people, and leaving residents and tourists alike without shelter, water, or sanitation access. Box 1 describes climate, land use, and other conditions that contributed to the devastating impact of the fire. Impacts on Maui's water systems are also discussed.

---

[20] US EPA's health-based screening assessments are non-specific risk assessments based on exposure and toxicity data (US EPA 2023c).

BOX 1. 2023 Wildfires in Maui

The wildfires in Maui in 2023 shocked the world; despite its tropical climate and the popular perception that the islands are wet and lush, all major islands in Hawaii have been experiencing declines in rainfall in both the wet and dry seasons (Keener et al. 2018; Stevens et al. 2022). Over 90% of the state is experiencing a drying trend (Frazier and Giambelluca 2016). On Maui, research has drawn a link between drying trends in the wet season at high elevation rain gauges and climate change (Longman et al. 2015). These and other factors, such as land conversion to non-native shrublands and widespread coverage of flammable invasive grasses around the islands, created conditions that scientists have warned for years increase the likelihood of wildfires (Kim 2023; Romero and Kovaleski 2023).

With Lahaina's leeward (i.e., southern, downwind) location on the island, at the confluence of a high-pressure system to the north, and Category 4 Hurricane Dora hundreds of miles to the south, conditions were primed for wildfires, and red flag warnings were issued statewide (McDaniel et al. 2023; Rush et al. 2023). While officials have yet to announce an official cause, some theorize that it was the reignition of a flare-up that was caused by a spark from electric lines along a road with an overgrown gully (Biesecker et al. 2023).

Effects on water systems were immediate and hampered efforts by residents and firefighters to combat the blaze. Power outages caused by high winds limited the ability to pump water, and while backup generators were utilized, hundreds of structures burning simultaneously rapidly depressurized the larger distribution system and hydrants ran dry (Baker et al. 2023). Poor communication with the public left many wondering why their water access was cut off during the crisis.

Residents within the burn area were told to avoid the water even where it still flowed through the pipes. "The language is stark—'there is no way to make [the water] safe,'" even with the use of filters (Peterson 2023). "It's alarming that it may be in the water system for a while," remarked a Maui resident (Peterson 2023). Filters "will remove some of [the extreme contamination] but levels that will be acutely and immediately toxic will get through," according to Purdue University researcher Andrew Whelton (Peterson 2023).

Air support to douse the flames was not possible due to high winds (Corkery et al. 2023). "In the end, the fire stopped only when it ran out of fuel at the ocean" reported *The New York Times* (Baker et al. 2023). The fire is now the deadliest US wildfire in 100 years, claiming at least nearly 100 lives and burning 3,000 structures, resulting in billions of dollars of damage (McDaniel et al. 2023; Knoll 2023).

5. Conclusion

The full impact of climate change on water and sanitation access, resources, infrastructure, and households in frontline communities now and into the future is not fully understood. Nonetheless, we do know that climate change is already having significant impacts on water and sanitation systems and resources across the United States. These impacts are expected to get worse and possibly lead to backsliding for frontline communities already suffering disproportionately and "first and worst" from the failure to provide water and sanitation for all. These communities are often overburdened while lacking the resources and capacity to prepare for and adapt to the impacts of climate change and its associated effects on water systems. This disparity leaves those communities disproportionately vulnerable to the impacts of water and sanitation system failures, such as a lack of access to clean water and sanitation services, or in need of alternative water supplies post-disaster. For frontline communities that currently lack water and sanitation, more effort is needed to fulfill the human right to water and sanitation and to ensure that solutions and strategies applied to secure these services are resilient to climate change.

Through documenting the state of knowledge on climate-change impacts to water and sanitation in the United States, we have identified six climate phenomena that pose immediate and future challenges for water and sanitation access for frontline communities. Table 1 provides a summary of our key findings on each of these six phenomena, including how each is expected to change in the future, the major known and projected impacts on water and sanitation, and, where available, information on any disproportionate impacts for frontline communities. While we have worked to be thorough in our investigation of each of these phenomena, we recognize that there may be additional impacts yet to be uncovered or that different geographies and communities will experience impacts differently than those presented here. We hope that this report can be updated and expanded as we learn more.

Additionally, this report is focused primarily on the impacts of climate change on water resources, water and sanitation systems, and water access. This synthesizes only one subset of the many and multi-faceted bodies of knowledge and ways of knowing about climate-related challenges faced by frontline communities. This report is only part 1 of the ***Water, Sanitation, and Climate Change in the United States*** series, and future reports will include a synthesis of the laws and policies in the United States that govern the delivery of water and sanitation in the face of climate change; an overview of barriers and challenges to equitable, climate-resilient water and sanitation; and a summary of documented strategies and approaches to overcome these barriers and challenges. Our goal is that this series will help to provide a foundation for the US WASH sector to incorporate and consider climate change in its work to close the water access gap.

TABLE 1. Summary of Climate Impacts from the Six Climate Phenomena

CLIMATE PHENOMENA	KEY FINDINGS
Extreme Temperatures	• Climate change is driving an increase in the frequency, magnitude, and duration of heatwaves, and in some cases, of extreme cold events in mid-latitude regions in the Northern Hemisphere. • Extreme heat events can have direct and indirect impacts on water supply and water systems, disrupting water access. • Direct impacts include evaporative losses in reservoirs and lakes and harmful cyanobacterial algal blooms, which can affect water access through reduced water sufficiency, physical accessibility, and safety. • Indirectly, extreme heat can increase water use and demand, also challenging water systems to ensure sufficient quantities of water. • Extreme heat contributes to conditions that create wildfires that affect water and sanitation infrastructure and access. • Frontline communities without access to water and sanitation are more at risk of severe health impacts during extreme heat events because water is an important tool for cooling and staying hydrated. • Extreme heat can compound health risks in vulnerable populations, such as the elderly, outdoor laborers, or those experiencing homelessness, especially if these groups already have insufficient access to water. • Extreme cold events have caused major disruptions to water access due to freezing and rupturing of water pipes and power outages. When water pipes are ruptured, systems can experience pressure loss, which in turn puts the distribution system at risk of contamination, making water unsafe. • Small water systems, which often serve rural communities, have had greater challenges coming back online after disruptions due to extreme cold. • Extreme cold events can impact septic drain systems that are not well insulated, even though they are below ground. • Extreme cold events can contribute to poor water quality through disruptions to nutrient cycling and from application of road salts that eventually wash into and contaminate waterways.

Drought	• Climate change is increasing the frequency, severity, and duration of droughts, which impacts water and sanitation, especially in low-income and rural communities. • Climate warming is progressing so-called “hot drought” and more arid conditions throughout an expanding area of the United States. • Increases in water demand and competition from people and nature, as supplies diminish, can put pressure on water sufficiency and physical availability. • Snow volumes across the Western United States are expected to decline approximately 25% by 2050, and low-to-no snow periods may become persistent within 35 to 60 years under a “business as usual” emissions scenario, reducing water availability for downstream communities. • Climate change, drought, and overexploitation of groundwater is resulting in reduced water availability, especially for rural communities dependent on shallow wells. • Climate change and drought are degrading both groundwater and surface water quality, which can make water unsafe to use or drink. • Drought impacts are not uniform and impact low-income communities and communities of color disproportionally. • Drought worsened by climate change will likely disproportionately raise the cost of water for frontline communities, raising barriers to access due to unaffordability.
Inland Flooding	• Flooding is among the most damaging and costliest disasters in the United States, which climate change will make worse for disproportionately impacted rural communities and communities of color. • Climate change makes the upkeep and maintenance of critical water infrastructure even more important to protect frontline communities from exposure to contaminants and loss of water and sanitation access from catastrophic failure during floods. • Major investment is needed in US water and sanitation infrastructure, and while recent investments are a step in that direction, estimates of needed investments far exceed those committed. • Rain-on-snow events that result in flooding are becoming more common and increasingly impacting water infrastructure, such as dams. • Extreme precipitation and flooding combined with wildfire and natural-resource extraction contribute to the destabilization of landscapes and flooding with deleterious impacts on water access for communities. • Flooding impacts water quality in all systems, and decentralized, onsite systems are often particularly vulnerable, especially in rural and low-income areas.

Sea Level Rise	• Climate-related rise in sea level is caused by thermal expansion of ocean waters and melting of land-based ice, such as glaciers and ice sheets. • The average sea level rise along US coastlines has been 28 cm (11 in.) from 1920–2020. • Sea level rise affects surface water and groundwater quality through saltwater intrusion, increasing treatment requirements or in some places making water unusable. • Saltwater intrusion can occur when water from the ocean travels upstream in coastal rivers, contaminating water supplies for communities beyond the coastline. • Wastewater systems and infrastructure that are located near the ocean are particularly vulnerable to sea level rise and, if taken offline, can cut sanitation access to entire communities. Research has found that as many as five times as many people will be impacted by damage to wastewater systems from sea level rise than due to direct flooding of residences. • In parts of coastal Alaska, a combination of sea level rise, sea ice decline, coastal erosion, and stronger storm surges have led to extreme flooding events and damage to water and wastewater infrastructure serving small, rural communities. • Higher water tables in coastal aquifers from sea level rise can inundate wastewater treatment facilities, causing damage, reducing access to sanitation.
Extreme Storms	• Extreme storms include a range of types of weather events; here we focus on tropical cyclones (hurricanes), convective storms (tornadoes), and severe coastal winter storms. • Hurricanes are increasing in intensity and frequency due to warming ocean temperatures. Rainfall associated with hurricanes is predicted to increase. • Climate change is also causing extreme storms to occur in new geographies. Hurricanes along the Atlantic are reaching further northward and tornado risks appear to be increasing in Missouri, Arkansas, Louisiana, Mississippi, Alabama, and Tennessee. • High winds, heavy rainfall, and storm surges that knock out power and cause flooding, landslides, and severe erosion can lead to the destruction or disruption of water and wastewater systems, causing loss of access and water contamination. • Widespread flooding from extreme storms has been associated with increased risk of exposure to bacterial and inorganic contaminates in water, harming human health, especially among populations that lack access such as those experiencing homelessness. • Research has documented a myriad of ways that extreme storms disproportionately impact Black, Hispanic, disabled, and low-income communities. For example, in Hurricane Harvey these communities suffered chemical exposures, lived in areas not covered by federal flood insurance, or were not able to prepare and respond due to disabilities or financial constraints, among others. • Climate change has reduced sea ice extent in space and time and caused rising seas. These changes amplify severe winter storms in places like Alaska, leading to flooding and damage to water and sanitation infrastructure in small, coastal communities. • Research has shown that damage from natural disasters increased wealth inequality in the United States, and that race, education, and homeownership all influence the severity of climate risks and the ability to adapt or recover after disasters.

Wildfires	• The potential for wildfires is increasing in frequency, geographic and temporal extent, and severity. • Many of the most at-risk homes and communities exist along the wildland-urban interface, the zone where human development ends and transitions into wildland. • Wildfires that burn houses and communities present a direct threat to water infrastructure during the fire and can place high demand on limited water resources to subdue and extinguish flames. • On the household scale, wildfires can melt and rupture water pipes and water meters. Domestic wells can also be damaged or destroyed. • On the community scale, wildfires can cause adverse effects to water intake systems, water-treatment systems, and reduce reservoir lifespan by worsening erosion and sedimentation. • After a wildfire occurs, surface-water supplies in the affected watershed and water within damaged distribution systems can be contaminated and unsafe to drink. • Additional treatment systems and processes to remediate the impacts of wildfire on water quality can be very costly, placing especially high burdens on low-income households. • Drinking water supplies may be at risk for years to decades after a wildfire. • Domestic wells can suffer many of the water quality challenges experienced by centralized drinking water systems post-fire. Yet these systems may not be able to recover as quickly as centralized systems. • For those who cannot afford testing of their well water to ensure it is safe after a fire, they may become reliant on more expensive water sources, like bottled water.

References

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 Society of Civil Engineers. 2021. “Dam Report Card.” American Society of Civil Engineers. https://infrastructurereportcard.org/wp-content/uploads/2020/12/Dams-2021.pdf.

American Water Works Association. 2022. “‘Utilities Helping Utilities’ Bring Water Heroes to Eastern Kentucky Flood Cleanup.” *American Water Works Association Connections*, September 7, 2022. https://www.awwa.org/AWWA-Articles/utilities-helping-utilities-bring-water-heroes-to-eastern-kentucky-flood-cleanup.

Assembly Bill No. 685. 2012. *Water Code*. http://www.leginfo.ca.gov/pub/11-12/bill/asm/ab_0651-0700/ab_685_bill_20120925_chaptered.pdf.

Associated Press. 2021. “Thousands Without Heat, Water After Tornadoes Kill Dozens.” WTTW News, December 13, 2021. https://news.wttw.com/2021/12/13/thousands-without-heat-water-after-tornadoes-kill-dozens.

Association of State Dam Safety Officials. 2023. “The Cost of Rehabilitating Dams in the U.S.” Lexington, KY: Association of State Dam Safety Officials. http://damsafety-prod.s3.amazonaws.com/s3fs-public/files/2023%20ASDSO%20Costs%20of%20Dam%20Rehab%20Report.pdf.

Bacon, John. 2017. “Why Puerto Rico Faces a Monumental Recovery Effort.” *USA TODAY*, September 26, 2017. https://www.usatoday.com/story/news/nation/2017/09/26/why-puerto-rico-faces-monumental-recovery-effort/703515001/.

Baker, Mike, Kellen Browning, and Nicholas Bogel-Burroughs. 2023. “As Inferno Grew, Lahaina’s Water System Collapsed.” *The New York Times*, August 22, 2023. https://www.nytimes.com/2023/08/13/us/lahaina-water-failure.html.

Barber, Timothy R., Christopher C. Lutes, Michiel R. J. Doorn, Phyllis C. Fuchsman, Hubert J. Timmenga, and Robert L. Crouch. 2003. “Aquatic Ecological Risks Due to Cyanide Releases from Biomass Burning.” *Chemosphere* 50 (3): 343–48. https://doi.org/10.1016/S0045-6535(02)00532-5.

Bellisle, Martha. 2022. “Climate Change, New Construction Mean More Ruinous Fires.” Associated Press, January 2, 2022. https://apnews.com/article/climate-wildfires-science-environment-environment-and-nature-8d111d6f6dfa9bfa78a2fe9659802826 .

Bessette-Kirton, Erin K., Corina Cerovski-Darriau, William H. Schulz, Jeffery A. Coe, Jason W. Kean, Jonathan W. Godt, Matthew A. Thomas, and K. Stephen Hughes. 2019. “Landslides Triggered by Hurricane Maria: Assessment of an Extreme Event in Puerto Rico.” *GSA Today* 29 (6): 4–10. https://doi.org/10.1130/GSATG383A.1.

Bhatia, Kieran T., Gabriel A. Vecchi, Thomas R. Knutson, Hiroyuki Murakami, James Kossin, Keith W. Dixon, and Carolyn E. Whitlock. 2019. “Recent Increases in Tropical Cyclone Intensification Rates.” *Nature Communications* 10 (1): 635. https://doi.org/10.1038/s41467-019-08471-z.

Biesecker, Michael, Jennifer McDermott, and Bernard Condon. 2023. “An Old Car Tire, Burnt Trees and a Utility Pole May Be Key in Finding How the Maui Wildfire Spread.” Associated Press, September 27, 2023. https://apnews.com/article/wildfires-maui-hawaii-electricity-utility-investigation-d9e1e84d5cc643d6bb2a2e362fe58ba0.

Billings, Stephen B., Emily A. Gallagher, and Lowell Ricketts. 2022. “Let the Rich Be Flooded: The Distribution of Financial Aid and Distress after Hurricane Harvey.” *Journal of Financial Economics* 146 (2): 797–819. https://doi.org/10.1016/j.jfineco.2021.11.006.

Bipartisan Policy Center. 2017. *Safeguarding Water Affordability.* Bipartisan Policy Center, September 2017. https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2019/03/BPC-Infrastructure-Safeguarding-Water-Affordability.pdf.

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.

Bolstad, Erika. 2022. “Climate Change Is Pushing Toxic Chemicals into Drinking Wells.” *Stateline,* April 28, 2022. https://pew.org/3LApCio.

Bostic, Darcy, Kristin B. Dobbin, R. A. Pauloo, Jessica Mendoza, Michael Kuo, and Jonathan London. 2020. *Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells*. UC Davis Center for Regional Change. https://pacinst.org/wp-content/uploads/2020/09/Sustainable-for-Whom_UC-Davis_Sept-2020.pdf.

Bostic, Darcy, Linda Mendez-Barrientos, Rich Pauloo, Kristin Dobbin, and Victoria MacClements. 2023. “Thousands of Domestic and Public Supply Wells Face Failure despite Groundwater Sustainability Reform in California’s Central Valley.” *Scientific Reports* 13 (14797). https://doi.org/10.1038/s41598-023-41379-9.

Bressler, Jonathan M., and Thomas W. Hennessy. 2018. “Results of an Arctic Council Survey on Water and Sanitation Services in the Arctic.” *International Journal of Circumpolar Health* 77 (1). https://doi.org/10.1080/22423982.2017.1421368.

Brown, Meredith J., Lauryn A. Spearing, Arkajyoti Roy, Jessica A. Kaminsky, and Kasey M. Faust. 2022. “Drivers of Declining Water Access in Alaska.” *ACS EST Water* 2 (8): 1411–21. https://doi.org/10.1021/acsestwater.2c00167.

Bruggers, James. 2019. “Appalachia’s Strip-Mined Mountains Face a Growing Climate Risk: Flooding.” *Inside Climate News*, November 21, 2019. https://insideclimatenews.org/news/21112019/appalachia-mountains-flood-risk-climate-change-coal-mining-west-virginia-extreme-rainfall-runoff-analysis/.

Burke, Marshall, Anne Driscoll, Sam Heft-Neal, Jiani Xue, Jennifer Burney, and Michael Wara. 2021. “The Changing Risk and Burden of Wildfire in the United States.” *Proceedings of the National Academy of Sciences* 118 (2). https://doi.org/10.1073/pnas.2011048118.

Burton, Carmen A., Todd M. Hoefen, Geoffrey S. Plumlee, Katherine L. Baumberger, Adam R. Backlin, Elizabeth Gallegos, and Robert N. Fisher. 2016. “Trace Elements in Stormflow, Ash, and Burned Soil Following the 2009 Station Fire in Southern California.” *PLOS ONE* 11 (5): e0153372. https://doi.org/10.1371/journal.pone.0153372.

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. 2023. “Statewide Summary: Locally Reported Dry Wells for Drought Assistance.” Dry Well Reporting System. https://mydrywatersupply.water.ca.gov/report/.

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. 2021. *Achieving the Human Right to Water in California*. California EPA. https://oehha.ca.gov/media/downloads/water/report/hrtwachievinghrtw2021f.pdf.

California State Water Resources Control Board. 2022. *California Drinking Water Needs Assessment*. California State Water Resources Control Board. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/needs.html.

Canadell, Josep G., Robbie Andrew, Philippe Ciais, Eric Davidson, Steven Davis, Pierre Friedlingstein, Robert B. Jackson, et al. 2021. “Global GHG Emissions and Budgets - Global Carbon Project (GCP).” In *United in Science 2021: A Multi-Organization High-Level Compilation of the Latest Climate Science Information*. World Meteorological Organization. https://wmo.int/publication-series/united-science-2021.

Cao, Zuohao, Huaqing Cai, and Guang J. Zhang. 2021. “Geographic Shift and Environment Change of U.S. Tornado Activities in a Warming Climate.” *Atmosphere (Basel)* 12 (5). https://doi.org/10.3390/atmos12050567.

Chakraborty, Jayajit, Sara E. Grineski, and Timothy W. Collins. 2019. “Hurricane Harvey and People with Disabilities: Disproportionate Exposure to Flooding in Houston, Texas.” *Social Science & Medicine* 226 (April): 176–81. https://doi.org/10.1016/j.socscimed.2019.02.039.

Chang, M., L. Erikson, K. Araujo, E.N. Asinas, S. Chisholm Hatfield, L.G. Crozier, E. Fleishman, et al. 2023. “Ch 27. Northwest.” In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/27/#key-message-.

Chapra, Steven C., Brent Boehlert, Charles Fant, Victor J. Jr. Bierman, Jim Henderson, David Mills, Diane M. L. Mas, et al. 2017. "Climate Change Impacts on Harmful Algal Blooms in U.S. Freshwaters: A Screening-Level Assessment." *Environmental Science & Technology* 51 (16): 8933–43. https://doi.org/10.1021/acs.est.7b01498.

Chavarria, Shaleene B., and David S. Gutzler. 2018. "Observed Changes in Climate and Streamflow in the Upper Rio Grande Basin." *JAWRA Journal of the American Water Resources Association* 54 (3): 644–59. https://doi.org/10.1111/1752-1688.12640.

Cho, Renee. 2021. "Attribution Science: Linking Climate Change to Extreme Weather." State of the Planet (blog). *Columbia Climate School*, October 4, 2021. https://news.climate.columbia.edu/2021/10/04/attribution-science-linking-climate-change-to-extreme-weather/.

Chow, A. T. -S., T. Karanfil, and R.A. Dahlgren. 2021. "Wildfires Are Threatening Municipal Water Supplies." *Eos*. August 12, 2021. http://eos.org/science-updates/wildfires-are-threatening-municipal-water-supplies.

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.

City of New York. 2023. A Livable Climate. OneNYC 2050, Volume 7 of 9. Mayor's Office on Climate and Environmental Justice, New York City. https://climate.cityofnewyork.us/reports/onenyc-2050/.

Clarke, L., L. Nichols, R. Vallario, M. Hejazi, J. Horing, A.C. Janetos, K. Mach, et al. 2018. "Sector Interactions, Multiple Stressors, and Complex Systems." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, edited by D.R. Reidmiller, D.R. Easterling, C.W. Avery, K.E. Kunkel, Lewis, Maycock, and B.C. Stewart, Volume II:638–68. Washington, D.C.: US Global Change Research Program. https://nca2018.globalchange.gov/chapter/17/.

Cohen, Judah, Laurie Agel, Mathew Barlow, Chaim I. Garfinkel, and Ian White. 2021. "Linking Arctic Variability and Change with Extreme Winter Weather in the United States." *Science* 373 (6559): 1116–21. https://doi.org/10.1126/science.abi9167.

Colley, Sarah K., Peter K.M. Kane, and Jacqueline MacDonald Gibson. 2019. "Risk Communication and Factors Influencing Private Well Testing Behavior: A Systematic Scoping Review." *International Journal of Environmental Research and Public Health* 16 (22): 4333. https://doi.org/10.3390/ijerph16224333.

Colmer, Jonathan, Ian Hardman, Jay Shimshack, and John Voorheis. 2020. "Disparities in PM2.5 Air Pollution in the United States." *Science* 369 (6503): 575–78. https://www.science.org/doi/10.1126/science.aaz9353.

Congressional Research Service. 2006. "Hurricane-Damaged Drinking Water and Wastewater Facilities: Impacts, Needs, and Response." Report for Congress RS22285. The Library of Congress. https://www.everycrsreport.com/files/20061215_RS22285_4c1ac949fff40f0e2a1dff6d7f79297888b66ef0.pdf.

Conrad, James W., and Valerie J. Harwood. 2022. “Sewage Promotes Vibrio Vulnificus Growth and Alters Gene Transcription in Vibrio Vulnificus CMCP6.” *Microbiology Spectrum* 10 (1): e01913-21. https://doi.org/10.1128/spectrum.01913-21.

Conroy-Ben, Otakuye, and Rain Richard. 2018. “Disparities in Water Quality in Indian Country.” *Journal of Contemporary Water Research & Education* 163 (1): 31–44. https://doi.org/10.1111/j.1936-704X.2018.03268.x.

Cook, Benjamin I., Jason E. Smerdon, Edward R. Cook, A. Park Williams, Kevin J. Anchukaitis, Justin S. Mankin, Kathryn Allen, et al. 2022. “Megadroughts in the Common Era and the Anthropocene.” *Nature Reviews Earth & Environment* 3 (11): 741–57. https://doi.org/10.1038/s43017-022-00329-1.

Cozzetto, Karen, K. Chief, K. Dittmer, M. Brubaker, R. Gough, K. Souza, F. Ettawageshik, et al. 2013. “Climate Change Impacts on the Water Resources of American Indians and Alaska Natives in the U.S.” In *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions*, edited by Julie Koppel Maldonado, Benedict Colombi, and Rajul Pandya, 120:569–84. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-05266-3_6.

Crownhart, Casey. 2021. “El Paso Was ‘Drought-Proof.’ Climate Change Is Pushing Its Limits.” *MIT Technology Review*. December 20, 2021. https://www.technologyreview.com/2021/12/20/1041307/el-paso-drought-climate-change/.

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.

DigDeep. 2021. United States WASH Sector Database: Building a Strong Coalition to Address Domestic Water, Sanitation, & Hygiene (WaSH). https://www.digdeep.org/wash-sector. Accessed September 1, 2023.

———. 2022. *Draining: The Economic Impact of America’s Hidden Water Crisis*. DigDeep. https://static1.squarespace.com/static/5e80f1a64ed7dc3408525fb9/t/62cc6d0e5f29d403367037ff/1657564437774/Draining_+The+Economic+Impact+of+America%27s+Hidden+Water+Crisis+%5BFULL+REPORT%5D.pdf.

Döll, Petra. 2009. “Vulnerability to the Impact of Climate Change on Renewable Groundwater Resources: A Global-Scale Assessment.” *Environmental Research Letters* 4 (3): 035006. https://doi.org/10.1088/1748-9326/4/3/035006.

Eichelberger, Laura, Subhabrata Dev, Tricia Howe, David L. Barnes, Eric Bortz, Brandon R. Briggs, Patricia Cochran, et al. 2021. “Implications of Inadequate Water and Sanitation Infrastructure for Community Spread of COVID-19 in Remote Alaskan Communities.” *Science of The Total Environment* 776 (July): 145842. https://doi.org/10.1016/j.scitotenv.2021.145842.

Emanuel, Kerry. 2021. “Response of Global Tropical Cyclone Activity to Increasing CO2: Results from Downscaling CMIP6 Models.” *Journal of Climate* 34 (1): 57–70. https://doi.org/10.1175/JCLI-D-20-0367.1.

Emelko, Monica B., Uldis Silins, Kevin D. Bladon, and Micheal Stone. 2011. “Implications of Land Disturbance on Drinking Water Treatability in a Changing Climate: Demonstrating the Need for ‘Source Water Supply and Protection’ Strategies.” *Water Research* 45 (2): 461–72. https://doi.org/10.1016/j.watres.2010.08.051.

Environment News Service. 2023. “WMO: September Shatters Planet’s Monthly Temperature Record.” *Environment News Service*, October 9, 2023. https://ens-newswire.com/99652-2/.

Every, Danielle, Jim McLennan, Elizabeth Osborn, and Chris Cook. 2021. “Experiences of Heat Stress While Homeless on Hot Summer Days in Adelaide.” *The Australian Journal of Emergency Management* 36 (4): 55–61. https://knowledge.aidr.org.au/resources/ajem-october-2021-experiences-of-heat-stress-while-homeless-on-hot-summer-days-in-adelaide/#:~:text=This%20paper%20reports%20findings%20from,or%20more%20heat%20stress%20symptoms.

Federal Emergency Management Agency. 2022. “Myths vs Facts: The True Cost of Flooding.” Preparedness Community, January 1, 2022. https://community.fema.gov/PreparednessConnect/s/article/Myths-vs-Facts-The-True-Cost-of-Flooding.

———. 2023. Kentucky Severe Storms, Flooding, Landslides, and Mudslides (DR-4663-KY). https://www.fema.gov/disaster/4663.

Feinstein, Laura. 2018. *Measuring Progress Toward Universal Access to Water and Sanitation in California.* Pacific Institute, September 2018. https://pacinst.org/publication/measuring-progress/.

Feinstein, Laura, Rapichan Phurisamban, Amanda Ford, Christine Tyler, and Ayana Crawford. 2017. *Drought and Equity in California*. Pacific Institute and The Environmental Justice Coalition for Water, January 2017. https://pacinst.org/wp-content/uploads/2017/01/PI_DroughtAndEquityInCA_Jan_2017.pdf.

Fentress, Ellen Ann and Richard Fausett. 2021. “‘You Can’t Bathe. You Can’t Wash.’ Water Crisis Hobbles Jackson, Miss., for Weeks.” *The New York Times*, March 12, 2021. https://www.nytimes.com/2021/03/12/us/jackson-mississippi-water-winter-storm.html.

Ficklin, Darren L., and Kimberly A. Novick. 2017. “Historic and Projected Changes in Vapor Pressure Deficit Suggest a Continental-scale Drying of the United States Atmosphere.” *Journal of Geophysical Research: Atmospheres* 122 (4): 2061–79. https://doi.org/10.1002/2016JD025855.

Flanagan, Sara V., and Yan Zheng. 2018. “Comparative Case Study of Legislative Attempts to Require Private Well Testing in New Jersey and Maine.” *Environmental Science & Policy* 85 (July): 40–46. https://doi.org/10.1016/j.envsci.2018.03.022.

Fleming, Elizabeth, Jeffrey L. Payne, William V. Sweet, Michael Craghan, John Haines, Juliette A. Finzi Hart, Heidi Stiller, and Ariana Sutton-Grier. 2018. “Chapter 8 : Coastal Effects. Impacts, Risks, and Adaptation in the United States: *The Fourth National Climate Assessment, Volume II*.” U.S. Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH8.

Flores, Aaron B., Alyssa Castor, Sara E. Grineski, Timothy W. Collins, and Casey Mullen. 2021. “Petrochemical Releases Disproportionately Affected Socially Vulnerable Populations along the Texas Gulf Coast after Hurricane Harvey.” *Population and Environment* 42 (3): 279–301. https://doi.org/10.1007/s11111-020-00362-6.

Frazier, Abby G., and Thomas W. Giambelluca. 2016. "Spatial Trend Analysis of Hawaiian Rainfall from 1920 to 2012." *International Journal of Climatology* 37 (5): 2522–31. https://doi.org/10.1002/joc.4862.

Galloway, Devin L., and Thomas J. Burbey. 2011. "Review: Regional Land Subsidence Accompanying Groundwater Extraction." *Hydrogeology Journal* 19: 1459–86. https://doi.org/10.1007/s10040-011-0775-5.

Gander, Malcolm J. 2022. "Climate Change and the Water Quality Threats Posed by the Emerging Contaminants Per- and Polyfluoroalkyl Substances (PFAS) and Microplastics." *Water International*, September 1–23. https://doi.org/10.1080/02508060.2022.2120255.

Gao, Xiao-Jian, and Xiao-Yong Wang. 2017. "Impacts of Global Warming and Sea Level Rise on Service Life of Chloride-Exposed Concrete Structures." *Sustainability* 9 (3): 460. https://doi.org/10.3390/su9030460.

Gariano, Stefano Luigi, and Fausto Guzzetti. 2016. "Landslides in a Changing Climate." *Earth-Science Reviews* 162 (November): 227–52. https://doi.org/10.1016/j.earscirev.2016.08.011.

Gensini, Vittorio A., and Harold E. Brooks. 2018. "Spatial Trends in United States Tornado Frequency." *Npj Climate and Atmospheric Science* 1 (38): 1–5. https://doi.org/10.1038/s41612-018-0048-2.

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.

Gilca, Andreea Florina, Carmen Teodosiu, Silvia Fiore, and Corina Petronela Musteret. 2020. "Emerging Disinfection Byproducts: A Review on Their Occurrence and Control in Drinking Water Treatment Processes." *Chemosphere* 259 (November): 127476. https://doi.org/10.1016/j.chemosphere.2020.127476.

Glazer, Yael R., Darrel M. Tremaine, Jay L. Banner, Margaret Cook, Robert E. Mace, John Nielsen-Gammon, Emily Grubert, et al. 2021. "Winter Storm Uri: A Test of Texas' Water Infrastructure and Water Resource Resilience to Extreme Winter Weather Events." *Journal of Extreme Events* 08 (04): 2150022. https://doi.org/10.1142/S2345737621500226.

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.

———. 1999. "The Human Right to Water." *Water Policy* 1 (5): 487–503. https://pacinst.org/wp-content/uploads/1999/01/basic_water_needs_human_right_to_water-2.pdf

———. 2023. *The Three Ages of Water*. New York, NY: PublicAffairs, Hachette Book Group. https://www.hachettebookgroup.com/titles/peter-gleick/the-three-ages-of-water/9781541702271/?lens=publicaffairs.

Godwin, Angela. 2022. "Rural Water: Coming Together in Time of Need." NRWA Content Portal. *Utility Operations* (blog). March 8, 2022. https://content.nrwa.org/utility-operations/article/15288153/rural-water-coming-together-in-time-of-need.

Gonzalez, Patrick, Gregg M. Garfin, David D. Breshears, Keely M. Brooks, Heidi E. Brown, Emile H. Elias, Amrith Gunasekara, et al. 2018. “Southwest.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, edited by David R. Reidmiller, David R. Easterling, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart, Volume II:1101–84. Washington, DC, USA: US Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH25.

Göransson, G., J. Norrman, and M. Larson. 2018. “Contaminated Landslide Runout Deposits in Rivers – Method for Estimating Long-Term Ecological Risks.” *Science of The Total Environment* 642 (November): 553–66. https://doi.org/10.1016/j.scitotenv.2018.06.078.

Gotham, Kevin Fox. 2014. “Racialization and Rescaling: Post-Katrina Rebuilding and the Louisiana Road Home Program: Racialization and Post-Katrina Rebuilding in Louisiana.” *International Journal of Urban and Regional Research* 38 (3): 773–90. https://doi.org/10.1111/1468-2427.12141.

Gowda, Prasanna H., Jean Steiner, Carolyn Olson, Mark Boggess, Tracey Farrigan, and Michael A. Grusak. 2018. “Chapter 10 : Agriculture and Rural Communities. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II.” U.S. Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH10.

Grant, Teddy. 2022. “Jackson, Mississippi, Water Shortage Crisis May Cost Billions of Dollars to Fix: Mayor.” *ABC News*, August 30, 2022. https://abcnews.go.com/US/jackson-mississippi-water-shortage-crisis-cost-billions-dollars/story?id=89061056.

Hagan, Eva. 2023. “The Flooding in Kentucky Is Getting Worse Because of Climate Change— Here’s Why.” *Green Matters*, August 17, 2023. https://www.greenmatters.com/weather-and-global-warming/is-kentucky-flooding-due-to-climate-change.

Haghani, Milad, Erica Kuligowski, Abbas Rajabifard, and Crystal A. Kolden. 2022. “The State of Wildfire and Bushfire Science: Temporal Trends, Research Divisions and Knowledge Gaps.” *Safety Science* 153 (September). https://doi.org/10.1016/j.ssci.2022.105797.

Hatchett, Benjamin J., and Daniel J. McEvoy. 2017. “Exploring the Origins of Snow Drought in the Northern Sierra Nevada, California.” *Earth Interactions* 22 (2). https://doi.org/10.1175/EI-D-17-0027.1.

Hayhoe, Katharine, Donald J. Wuebbles, David R. Easterling, David W. Fahey, Sarah Doherty, James P. Kossin, William V. Sweet, Russel S. Vose, and Michael F. Wehner. 2018. “Our Changing Climate.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, edited by D.R. Reidmiller, C.W. Avery, David R. Easterling, Kenneth E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Volume II:72–144. Washington, DC, USA: U.S. Global Change Research Program, Washington, DC. https://doi.org/10.7930/NCA4.2018.CH2.

Heberger, Matthew, Heather Cooley, Eli Moore, and Pablo Herrera. 2012. *The Impacts of Sea Level Rise on the San Franciso Bay*. California Energy Commission. https://pacinst.org/publication/the-impacts-of-sea level-rise-on-the-san-francisco-bay/.

Herring, Stephanie C, Nikolaos Christidis, Andrew Hoell, Peter A Stott, Andrew King, Thomas Knutson, John Nielsen-Gammon, and Friederike Otto. 2022. *Explaining Extreme Events of 2020 from a Climate Perspective*. American Meteorological Society. https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/explaining-extreme-events-from-a-climate-perspective/explaining-extreme-events-of-2020-from-a-climate-perspective/.

Hines, Jonas Z., Meredith A. Jagger, Thomas L. Jeanne, Nicole West, Andrea Winquist, Byron F. Robinson, Richard F. Leman, and Katrina Hedberg. 2018. “Heavy Precipitation as a Risk Factor for Shigellosis among Homeless Persons during an Outbreak — Oregon, 2015–2016.” *Journal of Infection* 76 (3): 280–85. https://doi.org/10.1016/j.jinf.2017.11.010.

Holden, Zachary A., Alan Swanson, Charles H. Luce, W. Matt Jolly, Marco Maneta, Jared W. Oyler, Dyer A. Warren, Russell Parsons, and David Affleck. 2018. “Decreasing Fire Season Precipitation Increased Recent Western US Forest Wildfire Activity.” *Proceedings of the National Academy of Sciences* 115 (36): E8349–57. https://doi.org/10.1073/pnas.1802316115.

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.

Hummel, Michelle A., Matthew S. Berry, and Mark T. Stacey. 2018. “Sea Level Rise Impacts on Wastewater Treatment Systems Along the U.S. Coasts.” *Earth’s Future* 6 (4): 622–33. https://doi.org/10.1002/2017EF000805.

Igini, Martina. 2022. “Water Shortage in Texas: Causes, Effects and Solutions.” Earth.Org. April 19, 2022. https://earth.org/water-shortage-in-texas/.

Indian Health Service. 2020. *Annual Report to the Congress of the United States on Sanitation Deficiency Levels for Indian Homes and Communities: Fiscal Year 2019*. Indian Health Service, Office of Environmental Health and Engineering. https://www.ihs.gov/sites/newsroom/themes/responsive2017/display_objects/documents/FY_2019_RTC_Sanitation_Deficiencies_Report.pdf.

Intergovernmental Panel on Climate Change. 2021. “Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.” Cambridge, UK and New York, NY, USA: Cambridge University Press. https://dx.doi.org/10.1017/9781009157896.

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, Lesley C., Rachael Novak, Roberto Delgado, Elizabeth Marino, Shannon McNeeley, Christopher Narducci, Julie Raymond-Yakoubian, Loretta Singletary, and Kyle Powys Whyte. 2018. “Tribes and Indigenous Peoples.” In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment,* edited by David Reidmiller, Christopher W. Avery, David R. Easterling, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart, Volume II:572–603. Washington, DC, USA: US Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH15.

Jay, A., A.R. Crimmins, C.W. Avery, T.A. Dahl, R.S. Dodder, B.D. Hamlington, A. Lustig, et al. 2023. "Ch 1. Overview." In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/#overview.

Johnson, Adelaide C., James Noel, David P. Gregovich, Linda E. Kruger, and Brian Buma. 2019. "Impacts of Submerging and Emerging Shorelines on Various Biota and Indigenous Alaskan Harvesting Patterns." *Journal of Coastal Research* 35 (4): 765–75. https://doi.org/10.2112/JCOASTRES-D-18-00119.1.

Jones, Patricia A, and Amber Moulton. 2016. "The Invisible Crisis: Water Unaffordability in the United States." Unitarian Universalist Service Committee. https://policycommons.net/artifacts/3760750/the-invisible-crisis/4566299/.

Kaysen. 2021. "Holding Back the Floodwaters." *The New York Times*, September 24, 2021. https://www.nytimes.com/2021/09/24/realestate/climate-change-basement-flooding-home-repair.html.

Keane, Robert E., Kevin C. Ryan, Tom T. Veblen, Craig D. Allen, Jessie Logan, and Brad Hawkes. 2002. *Cascading Effects of Fire Exclusion in the Rocky Mountain Ecosystems: A Literature Review*. General Technical Report RMRS-GTR-91. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://www.fs.usda.gov/research/treesearch/5132.

Keener, Victoria, David Helweg, Susan Asam, Seema Balwani, Burkett, Thomas Giambelluca, Zena Grecni, Malia Nobrega-Olivera, Jeffrey Polovina, and Gordon Tribble. 2018. "Hawai'i and U.S.-Affiliated Pacific Islands." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, edited by David R. Reidmiller, Christopher W. Avery, David R. Easterling, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart, 1242–1308. Washington, DC, USA: US Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH27.

Kenning, Chris, Connor Giffin, and James Bruggers. 2022. "'I Can't Do It Again': Can Appalachia Blunt the Devastating Impacts of More Flooding, Climate Change?" *USA Today*, August 8, 2022. https://www.usatoday.com/story/news/nation/2022/08/07/kentucky-flooding-appalachia-climate-change/10215762002/.

Kim, Shi En. 2023. "How Swaths of Invasive Grass Made Maui's Fires So Devastating." *Smithsonian Magazine*, August 15, 2023. https://www.smithsonianmag.com/smart-news/how-swaths-of-invasive-grass-made-mauis-fires-so-devastating-180982729/.

Kjellstrom, Tord, Chris Freyberg, Bruno Lemke, Matthias Otto, and David Briggs. 2018. "Estimating Population Heat Exposure and Impacts on Working People in Conjunction with Climate Change." *International Journal of Biometeorology* 62 (March): 291–306. https://doi.org/10.1007/s00484-017-1407-0.

Knoll, Corina. 2023. "Maui Fire Death Toll Drops to 97 After Weeks of DNA Review." *The New York Times*, September 15, 2023. https://www.nytimes.com/2023/09/15/us/maui-fire-death-toll-drops.html.

Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner. 2017. “Extreme Storms.” In *Climate Science Special Report: Fourth National Climate Assessment, Volume1*, p.257-276. Washington, D.C.: U.S. Global Change Research Program. https://science2017.globalchange.gov/chapter/9/.

Krainz, Trevor, and Shunfu Hu. 2022. “Spatiotemporal Shifts in Tornadic Activity of 1958–2017 in the Central United States.” *Papers in Applied Geography* 8 (4): 468–82. https://doi.org/10.1080/23754931.2022.2083979.

Kunkel, Kenneth E., Thomas R. Karl, Michael F. Squires, Xungang Yin, Steve T. Stegall, and David R. Easterling. 2020. “Precipitation Extremes: Trends and Relationships with Average Precipitation and Precipitable Water in the Contiguous United States.” *Journal of Applied Meteorology and Climatology* 59 (1): 125–42. https://doi.org/10.1175/JAMC-D-19-0185.1.

Lall, Upmanu, Thomas Johnson, Peter Colohan, Amir Aghakouchak, Sankar Arumugam, Casey Brown, Gregory J. Mccabe, and Roger S. Pulwarty. 2018. “Water.” In *Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment*, edited by David R. Reidmiller, Christopher W. Avery, David R. Easterling, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart, Volume II:145–73. Washington, DC, USA: US Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH3.

Landen, Xander. 2022. “Jackson Has A $1 Billion Water Problem—Feds Gave Mississippi $75 Million.” *Newsweek*, September 1, 2022. https://www.newsweek.com/mississippi-got-75m-water-projectsjacksons-system-needed-1b-1739045.

Leung, L.R., Adam Terando, R. Joseph, G. Tselioudis, L.M. Bruhwiler, B. Cook, C. Deser, et al. 2023. “Ch 3. Earth Systems Processes.” In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/3/.

Levy, Barry S., and Cora Roelofs. 2019. “Impacts of Climate Change on Workers’ Health and Safety.” In *Oxford Research Encyclopedia of Global Public Health*. https://doi.org/10.1093/acrefore/9780190632366.013.39.

Levy, Zeno F., Bryant C. Jurgens, Karen R. Burow, Stefan A. Voss, Kirsten E. Faulkner, Jose A. Arroyo-Lopez, and Miranda S. Fram. 2021. “Critical Aquifer Overdraft Accelerates Degradation of Groundwater Quality in California’s Central Valley During Drought.” *Geophysical Research Letters* 48 (17): e2021GL094398. https://doi.org/10.1029/2021GL094398.

Li, Dongyue, Melissa L. Wrzesien, Michael Durand, Jennifer Adam, and Dennis P. Lettenmaier. 2017. “How Much Runoff Originates as Snow in the Western United States, and How Will That Change in the Future?” *Geophysical Research Letters* 44 (12): 6163–72. https://doi.org/10.1002/2017GL073551.

Li, Na, Yunlin Zhang, Yibo Zhang, Kun Shi, Haiming Qian, Huayin Yang, Yongkang Niu, et al. 2023. “The Unprecedented 2022 Extreme Summer Heatwaves Increased Harmful Cyanobacteria Blooms.” *Science of The Total Environment* 896 (October): 165312. https://doi.org/10.1016/j.scitotenv.2023.165312.

Liu, Pang-Wei, James S. Famiglietti, Adam J. Purdy, Kyra H. Adams, Avery L. McEvoy, John T. Reager, Rajat Bindlish, David N. Wiese, Cédric H. David, and Matthew Rodell. 2022. “Groundwater Depletion in California’s Central Valley Accelerates during Megadrought.” *Nature Communications* 13 (1): 7825. https://doi.org/10.1038/s41467-022-35582-x.

Lombard, Melissa A., Johnni Daniel, Zuha Jeddy, Lauren E. Hay, and Joseph D. Ayotte. 2021. “Assessing the Impact of Drought on Arsenic Exposure from Private Domestic Wells in the Conterminous United States.” *Environmental Science & Technology* 55 (3): 1822–31. https://doi.org/10.1021/acs.est.9b05835.

London, Jonathan, Amanda Fencl, Sara Watterson, Jennifer Jarin, Alfonso Aranda, Aaron King, Camille Pannu, et al. 2018. *The Struggle for Water Justice in California’s San Joaquin Valley: A Focus on Disadvantaged Unincorporated Communities*. UC Davis Center for Regional Change, February 2018. https://regionalchange.ucdavis.edu/sites/g/files/dgvnsk986/files/inline-files/The%20Struggle%20for%20Water%20Justice%20FULL%20REPORT.pdf.

Longman, Ryan J., Henry F. Diaz, and Thomas W. Giambelluca. 2015. “Sustained Increases in Lower-Tropospheric Subsidence over the Central Tropical North Pacific Drive a Decline in High-Elevation Rainfall in Hawaii.” *Journal of Climate* 28 (22): 8743–59. https://www.jstor.org/stable/26195721.

Lovato, Ny Keely. 2022. “Legal Mapping for Resilience Navajo Nation.” Student paper. Program on Human Rights and the Global Economy, Northeastern University School of Law.

Lynch, Jamiel, and Rachel Ramirez. 2023. “Army Corps Will Barge in up to 36 Million Gallons of Freshwater a Day as Saltwater Threatens Drinking Water South of New Orleans.” *CNN*, September 24, 2023. https://www.cnn.com/2023/09/23/us/freshwater-new-orleans-saltwater-mississippi-river/index.html.

MacDonald Gibson, Jacqueline, and Kelsey J. Pieper. 2017. “Strategies to Improve Private-Well Water Quality: A North Carolina Perspective.” *Environmental Health Perspectives* 125 (7): 076001. https://doi.org/10.1289/EHP890.

Mach, Katharine J., R. Vallario, J.R. Arnold, C Brelsford, K.V. Calvin, A.N. Flores, J. Gao, et al. 2023. “Ch 18. Sector Interactions, Multiple Stressors, and Complex Systems.” In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/18/.

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.

Mann, Michael E., and Peter H. Gleick. 2015. “Climate Change and California Drought in the 21st Century.” *Proceedings of the National Academy of Sciences* 112 (13): 3858–59. https://doi.org/10.1073/pnas.1503667112.

Markon, Carl J., Steve T. Gray, Matthew Berman, Laura Eerkes-Medrano, Thomas Hennessy, Henry P. Huntington, Jeremy Littell, Molly McCammon, Richard Thoman, and Sarah Trainor. 2018. "Alaska." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, edited by David R. Reidmiller, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart, 1185–1241. Washington, DC, USA: US Global Change Research Program. https://doi.org/10.7930/NCA4.2018.CH26.

Martin, Justin T., Gregory T. Pederson, Connie A. Woodhouse, Edward R. Cook, Gregory J. McCabe, Kevin J. Anchukaitis, Erika K. Wise, et al. 2020. "Increased Drought Severity Tracks Warming in the United States' Largest River Basin." *Proceedings of the National Academy of Sciences* 117 (21): 11328–36. https://doi.org/10.1073/pnas.1916208117.

Marvel, Kate, W Su, Roberto Delgado, S Aarons, A Chatterjee, M.E Garcia, Z Hausfather, et al. 2023. "Ch 2. Climate Trends." In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/2/.

May, C.L., M. Osler, H.F. Stockdon, P.L. Barnard, J.A. Callahan, R.C. Collini, C.M. Ferreira, et al. 2023. "Ch 9. Coastal Effects." In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/9/.

McDaniel, Justine, Maham Javaid, and Andrea Salcedo. 2023. "What to Know about Maui Wildfires, the Deadliest in the U.S. in 100 Years." *The Washington Post*, August 16, 2023, sec. Climate. https://www.washingtonpost.com/weather/2023/08/16/maui-wildfires-damage-explained/.

McGraw, George. 2020. "The United States Needs Its Own WASH Sector." Philanthropy News Digest, June 29, 2020. https://philanthropynewsdigest.org/columns/ssir-pnd/the-united-states-needs-its-own-wash-sector.

McNeeley, Shannon M. 2014. "A 'Toad's Eye' View of Drought: Regional Socio-Natural Vulnerability and Responses in 2002 in Northwest Colorado." *Regional Environmental Change* 14 (4): 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.

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.

Meadows, Robin. 2022. "How Do Wildfires Affect Water Systems?" *ACS Central Science* 8 (5): 504–6. https://doi.org/10.1021/acscentsci.2c00511.

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.

Miami-Dade County and Florida Department of Health. 2018. *Septic Systems Vulnerable to Sea Level Rise*. No. R-911-16. Miami-Dade County Department of Regulatory & Economic Resources, Miami-Dade County Water and Sewer Department, Florida Department of Health in Miami-Dade County. https://www.miamidade.gov/green/library/vulnerability-septic-systems-sea level-rise.pdf.

Miller, Olivia L., Matthew P. Miller, Patrick C. Longley, Jay R. Alder, Lindsay A. Bearup, Tom Pruitt, Daniel K. Jones, Annie L. Putman, Christine A. Rumsey, and Tim McKinney. 2021. "How Will Baseflow Respond to Climate Change in the Upper Colorado River Basin?" *Geophysical Research Letters* 48 (22). https://doi.org/10.1029/2021GL095085.

Milly, P. C. D., and K. A. Dunne. 2020. "Colorado River Flow Dwindles as Warming-Driven Loss of Reflective Snow Energizes Evaporation." *Science* 367 (6483): 1252–55. https://doi.org/10.1126/science.aay9187.

Moody, John A., and Deborah A. Martin. 2001. "Initial Hydrologic and Geomorphic Response Following a Wildfire in the Colorado Front Range." *Earth Surface Processes and Landforms* 26 (10): 1049–70. https://doi.org/10.1002/esp.253.

Moody, John A, and Deborah A Martin. 2004. "Wildfire Impacts on Reservoir Sedimentation in the Western United States." In *Proceedings of the Ninth International Symposium on River Sedimentation*, 1095–1102. Yichang, China. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=499a81ed5acb1024cd2de7e48831a948ec9c001c.

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.

Murray, Andrew, Alexander Hall, James Weaver, and Fran Kremer. 2021. "Methods for Estimating Locations of Housing Units Served by Private Domestic Wells in the United States Applied to 2010." *JAWRA Journal of the American Water Resources Association* 57 (5): 828–43. https://doi.org/10.1111/1752-1688.12937.

Musselman, Keith N., Flavio Lehner, Kyoko Ikeda, Martyn P. Clark, Andreas F. Prein, Changhai Liu, Mike Barlage, and Roy Rasmussen. 2018. "Projected Increases and Shifts in Rain-on-Snow Flood Risk Over Western North America." *Nature Climate Change* 8 (9): 808–12. https://doi.org/10.1038/s41558-018-0236-4.

National Aeronautics and Space Administration. 2023. "NASA Clocks July 2023 as Hottest Month on Record Ever Since 1880." Global Climate Change, August 14, 2023. https://climate.nasa.gov/news/3279/nasa-clocks-july-2023-as-hottest-month-on-record-ever-since-1880.

National Council on Aging. 2021. "Hydration for Older Adults, How to Stay Hydrated for Better Health." August 23, 2021. https://www.ncoa.org/article/how-to-stay-hydrated-for-better-health.

National Drought Mitigation Center. n.d. “US Drought Monitor.” US Drought Monitor. n.d. https://droughtmonitor.unl.edu/CurrentMap.aspx.

National Oceanic and Atmospheric Administration. 2023a. What Is a Hurricane? National Ocean Service, January 2023. https://oceanservice.noaa.gov/facts/hurricane.html.

———. 2023b. “July 2023 Brought Record-High Temperatures, Devastating Floods across the U.S.” August 8, 2023. https://www.noaa.gov/stories/july-2023-brought-record-high-temperatures-devastating-floods-across-us.

———. 2023c. “The World Just Sweltered through Its Hottest August on Record.” September 14, 2023. https://www.noaa.gov/news/world-just-sweltered-through-its-hottest-august-on-record.

———. 2023d. “Topping the Charts: September 2023 Was Earth’s Warmest September in 174-Year Record.” October 13, 2023. https://www.noaa.gov/news/topping-charts-september-2023-was-earths-warmest-september-in-174-year-record.

———. 2023e. “The Planet Just Had Its Warmest October on Record.” November 15, 2023. https://www.noaa.gov/news/planet-just-had-its-warmest-october-on-record.

———. 2023f. “Earth Had Its Warmest November on Record.” December 14, 2023. https://www.noaa.gov/news/earth-had-its-warmest-november-on-record.

———. n.d. Cold Weather Safety. National Weather Service. NOAA’s National Weather Service. n.d. https://www.weather.gov/safety/cold. Accessed September 1, 2023.

National Oceanic and Atmospheric Administration National Centers for Environmental Information. 2022. *Assessing the U.S. Climate in August 2022*. September 8, 2022. https://www.ncei.noaa.gov/news/national-climate-202208.

National Weather Service. 2022. “Historic July 26th-July 30th, 2022, Eastern Kentucky Flooding.” NWS Web News Stories. NOAA’s National Weather Service. 2022. https://www.weather.gov/jkl/July2022Flooding.

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.

Neuman, Scott. 2022. “The Crisis in Jackson Shows How Climate Change Is Threatening Water Supplies.” *National Public Radio*, September 7, 2022. https://www.npr.org/2022/09/07/1121178780/jackson-mississippi-water-crisis-climate-change.

Nieuwenhuijsen, Mark J., James Grellier, Rachel Smith, Nina Iszatt, James Bennett, Nicky Best, and Mireille Toledano. 2009. “The Epidemiology and Possible Mechanisms of Disinfection By-Products in Drinking Water.” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 367 (1904): 4043–76. https://doi.org/10.1098/rsta.2009.0116.

Olson, Emily and Rachel Treisman. 2023. “Tropical Storm Hilary moves on from California, leaving a trail of damage and debris.” NPR. August 21, 2023. https://www.npr.org/2023/08/21/1195032403/hilary-california-flooding-storm-monday.

Oregon Health Authority. 2023. Lower Umatilla Basin Groundwater Management Area Domestic Wells Project. State Government Pu. Domestic Well Safety, Oregon Drinking Water Services. 2023. https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/SOURCEWATER/DOMESTICWELLSAFETY/Pages/Wildfire-Impacted-Domestic-Well-Testing.aspx.

———. n.d. Groundwater Protection and Well Stewardship: Oregon's Domestic Well Safety Program. n.d. https://www.oregon.gov/oha/PH/HealthyEnvironments/DrinkingWater/SourceWater/DomesticWellSafety/Pages/index.aspx. Accessed June 13, 2023.

Oregon Secretary of State and Oregon Audits Division. 2023. Advisory Report: State Leadership Must Take Action to Protect Water Security for All Oregonians. 2023–04. https://sos.oregon.gov/audits/Pages/audit-advisory-report-water-security.aspx#:~:text=This%20advisory%20report%20addresses%20gaps,improve%20these%20gaps%20in%20governance.

Osezua, Michael, Shree Om Bade, Emmanuel Gyimah, and Olusegun Stanley Tomomewo. 2023. "Impact of Climate Change on the Water Resources, Lake Powell, United States." *American Journal of Water Resources* 11 (3): 103–11. https://doi.org/10.12691/ajwr-11-3-3.

Overpeck, Jonathan T., and Bradley Udall. 2020. "Climate Change and the Aridification of North America." *Proceedings of the National Academy of Sciences* 117 (22): 11856–58. https://doi.org/10.1073/pnas.2006323117.

Paerl, Hans W., and Jef Huisman. 2009. "Climate Change: A Catalyst for Global Expansion of Harmful Cyanobacterial Blooms." *Environmental Microbiology Reports* 1 (1): 27–37. https://doi.org/10.1111/j.1758-2229.2008.00004.x.

Paltan, Homero, Duane Waliser, Wee Ho Lim, Bin Guan, Dai Yamazaki, Raghav Pant, and Simon Dadson. 2017. "Global Floods and Water Availability Driven by Atmospheric Rivers." *Geophysical Research Letters* 44 (20). https://doi.org/10.1002/2017GL074882.

Patterson, Lauren A, and Martin W Doyle. 2020. 2020 Aspen-Nicholas Water Forum: Water Affordability and Equity Briefing Document. Duke Nicholas Institute for Environmental Policy Solutions. https://nicholasinstitute.duke.edu/publications/2020-aspen-nicholas-water-forum-water-affordability-and-equity-briefing-document.

Paul, M. J., S. D. LeDuc, M. G. Lassiter, L. C. Moorhead, P. D. Noyes, and S. G. Leibowitz. 2022. "Wildfire Induces Changes in Receiving Waters: A Review with Considerations for Water Quality Management." *Water Resources Research* 58 (9). https://doi.org/10.1029/2021WR030699.

Pauloo, R. A., A. Escriva-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, et al. 2023. "Ch 4. Water." In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://doi.org/10.7930/NCA5.2023.CH4.

Penn, Henry J. F., S. Craig Gerlach, and Philip A. Loring. 2016. "Seasons of Stress: Understanding the Dynamic Nature of People's Ability to Respond to Change and Surprise." *Weather, Climate, and Society* 8 (4): 435–46. https://doi.org/10.1175/WCAS-D-15-0061.1.

Perera, Nandana, Bahram Gharabaghi, and Ken Howard. 2013. "Groundwater Chloride Response in the Highland Creek Watershed Due to Road Salt Application: A Re-Assessment after 20years." *Journal of Hydrology* 479 (February): 159–68. https://doi.org/10.1016/j.jhydrol.2012.11.057.

Perkins-Kirkpatrick, S. E., and S. C. Lewis. 2020. "Increasing Trends in Regional Heatwaves." *Nature Communications* 11 (3357): 1–8. https://doi.org/10.1038/s41467-020-16970-7.

Peterson, Brittany. 2023. "Maui Water Is Unsafe Even with Filters, One of the Lessons Learned from Fires in California." The Associated Press, August 19, 2023. https://apnews.com/article/wildfire-water-contamination-maui-hawaii-fires-c547955833ceaf86af8c3f1553f1f546.

Plaquemines Parish Government. 2022. State of Emergency - Saltwater Wedge Intrusion Plaquemines Parish, LA, Civic Alert. https://www.plaqueminesparish.com/DocumentCenter/View/1822/State-of-Emergency_Saltwater-Wedge-Intrusion-9_28_22?bidId=.

Pörtner, H.-O., D.C. Roberts, H. Adams, I. Adelekan, C. Adler, R. Adrian, P. Aldunce, et al. 2022. "Technical Summary." In *Climate Change 2022: Impacts, Adaptation and Vulnerability*, 37–118. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. UK and New York, NY: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/chapter/technical-summary/.

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). https://doi.org/10.1002/aws2.1183.

Qin, Boqiang, Hans W. Paerl, Justin D. Brookes, Jianguo Liu, Erik Jeppesen, Guangwei Zhu, Yunlin Zhang, Hai Xu, Kun Shi, and Jianming Deng. 2019. "Why Lake Taihu Continues to Be Plagued with Cyanobacterial Blooms through 10 Years (2007–2017) Efforts." *Science Bulletin* 64 (6): 354–56. https://doi.org/10.1016/j.scib.2019.02.008.

Ramin, Brodie, and Tomislav Svoboda. 2009. "Health of the Homeless and Climate Change." *Journal of Urban Health* 86 (July): 654–64. https://doi.org/10.1007/s11524-009-9354-7.

Rojas, Rick. 2022. "Mississippi's Capital Loses Water as a Troubled System Faces a Fresh Crisis." *The New York Times*, August 30, 2022. https://www.nytimes.com/2022/08/30/us/mississippi-jackson-water.html.

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*. DigDeep and U.S. Water Alliance. https://urbanwaterslearningnetwork.org/resources/closing-the-water-access-gap-in-the-united-states-a-national-action-plan-nov-2019/.

Romero, Simon. 2022. "How New Mexico's Largest Wildfire Set Off a Drinking Water Crisis." *The New York Times,* September 26, 2022. https://www.nytimes.com/2022/09/26/us/new-mexico-las-vegas-fire-water.html.

Romero, Simon, and Serge F. Kovaleski. 2023. "How Invasive Plants Caused the Maui Fires to Rage." *The New York Times*, August 13, 2023. https://www.nytimes.com/2023/08/13/us/hawaii-wildfire-factors.html.

Rosenthal, Zach, and Jacob Feuerstein. 2022. “Strongest Storm in Decades Battering Alaska.” *Washington Post*, September 17, 2022. https://www.washingtonpost.com/climate-environment/2022/09/16/coastal-alaska-storm-surge-flooding-winds/.

Rowles III, Lewis Stetson, Areeb I. Hossain, Isac Ramirez, Noah J. Durst, Peter M. Ward, Mary Jo Kirisits, Isabel Araiza, Desmond F. Lawler, and Navid B. Saleh. 2020. “Seasonal Contamination of Well-Water in Flood-Prone Colonias and Other Unincorporated U.S. Communities.” *The Science of the Total Environment* 740 (October): 140111. https://doi.org/10.1016/j.scitotenv.2020.140111.

Rush, Claire, Seth Borenstein, and Jennifer McDermott. 2023. “Maui’s Fire Became Deadly Fast. Climate Change, Flash Drought, Invasive Grass and More Fueled It.” The Associated Press, August 9, 2023. https://apnews.com/article/hawaii-wildfires-climate-change-92c0930be7c28ec9ac71392a83c87582.

Russo, Tess A., and Upmanu Lall. 2017. “Depletion and Response of Deep Groundwater to Climate-Induced Pumping Variability.” *Nature Geoscience* 10 (2): 105–8. https://doi.org/10.1038/ngeo2883.

Samuels, Alex. 2021. “Nearly 12 Million Texans Now Face Water Disruptions. The State Needs Residents to Stop Dripping Taps.” *The Texas Tribune*, February 17, 2021. https://www.texastribune.org/2021/02/17/texas-water-boil-notices/.

Scanlon, Bridget R., Claudia C. Faunt, Laurent Longuevergne, Robert C. Reedy, William M. Alley, Virginia L. McGuire, and Peter B. McMahon. 2012. “Groundwater Depletion and Sustainability of Irrigation in the US High Plains and Central Valley.” *Proceedings of the National Academy of Sciences* 109 (24): 9320–25. https://doi.org/10.1073/pnas.1200311109.

Schimpf, Cordelia, and Curtis Cude. 2020. “A Systematic Literature Review on Water Insecurity from an Oregon Public Health Perspective.” *International Journal of Environmental Research and Public Health* 17 (3). https://doi.org/10.3390/ijerph17031122.

Schreiner and Galofaro. 2021. “Thousands without Heat, Water after Tornadoes Kill Dozens.” Associated Press, December 13, 2021. https://apnews.com/article/tornadoes-business-arkansas-kentucky-mayfield-b6ef6a901cc2e4552e760a36c749937c.

Scott, Roxanne. 2022. “Sewer Backups, Increasing from Climate Change, Are Costing City’s Homeowners.” Investigative Journalism. *City Limits*, October 12, 2022. https://citylimits.org/2022/10/12/sewer-backups-increasing-from-climate-change-are-costing-citys-homeowners/.

Scott, Julia, Alexis Wagner and Genelle Winter. 2017. *Metlakatla Indian Community Climate Change Adaptation Plan 2017-2027*. Metlakatla Indian Community. https://www.cakex.org/sites/default/files/documents/MIC%20CCAP%20secondary%20proof.pdf.

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, et al. 2021. “Weather and Climate Extreme Events in a Changing Climate.” In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 1513–1766. Cambridge, UK and New York, NY, USA: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter11.pdf.

Shafiei Shiva, J., and D. G. Chandler. 2020. “Assessing Impacts of Heatwaves on Urban Water Distribution Systems: Planning for a Resilient Design Approach.” In *American Geophysical Union*. https://ui.adsabs.harvard.edu/abs/2020AGUFMGC0560013S.

Shindell, Drew, Yuqiang Zhang, Melissa Scott, Muye Ru, Krista Stark, and Kristie L. Ebi. 2020. “The Effects of Heat Exposure on Human Mortality Throughout the United States.” *GeoHealth* 4 (4). https://doi.org/10.1029/2019GH000234.

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.

Smiley, Kevin T., Ilan Noy, Michael F. Wehner, Dave Frame, Christopher C. Sampson, and Oliver E. J. Wing. 2022. “Social Inequalities in Climate Change-Attributed Impacts of Hurricane Harvey.” *Nature Communications* 13 (1): 3418. https://doi.org/10.1038/s41467-022-31056-2.

Smith, Hugh G., Gary J. Sheridan, Patrick N.J. Lane, Petter Nyman, and Shane Haydon. 2011. “Wildfire Effects on Water Quality in Forest Catchments: A Review with Implications for Water Supply.” *Journal of Hydrology* 396 (1–2): 170–92. https://www.researchgate.net/publication/260918379_Wildfire_effects_on_water_quality_in_forest_catchments_A_review_with_implications_for_water_supply.

Smith, Mike. 2023. “Carlsbad Issues Water Restrictions Due to Relentless Heat, Lack of Rain.” *Carlsbad Current-Argus*, August 9, 2023. https://www.currentargus.com/story/news/local/2023/08/09/carlsbad-issues-stage-one-water-restrictions-from-lack-of-rain-heat-drought-outdoor-watering/70558502007/.

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.

Solomon, Gina M., Susan Hurley, Catherine Carpenter, Thomas M. Young, Paul English, and Peggy Reynolds. 2021. “Fire and Water: Assessing Drinking Water Contamination After a Major Wildfire.” *ACS ES&T Water* 1 (8): 1878–86. https://doi.org/10.1021/acsestwater.1c00129.

Status of Tribes and Climate Change Working Group. 2021. *The Status of Tribes and Climate Change Report*. Institute for Tribal Environmental Professionals, Northern Arizona University. http://nau.edu/stacc2021.

Stevens, L.E., R. Frankson, K.E. Kunkel, P.-S. Chu, and W. Sweet. 2022. “Hawai’i State Climate Summary 2022.” NOAA Technical Report NESDIS 150-HI. Silver Spring, Maryland: NOAA/NESDIS. https://statesummaries.ncics.org/chapter/hi/.

Stewart, Iris T., Jacqueline Rogers, and Anne Graham. 2020. “Water Security under Severe Drought and Climate Change: Disparate Impacts of the Recent Severe Drought on Environmental Flows and Water Supplies in Central California.” *Journal of Hydrology X* 7 (April): 100054. https://doi.org/10.1016/j.hydroa.2020.100054.

Stork, Ron, Chris Shutes, Gary Reedy, Katrina Schneider, Dave Steindorf, and Eric Wesselman. 2017. *The Oroville Dam 2017 Spillway Incident and Lessons from the Feather River Basin*. Friends of the River, California Sportsfishing Protection Alliance, South Yuba River Citizens League, and American Whitewater. https://www.friendsoftheriver.org/wp-content/uploads/2017/09/Executive-Summary-The-Oroville-Dam-2017-Spillway-Incident-Lessons-from-the-Feather-River-Basin.pdf.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, et al. 2022. Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 1. Silver Spring, Maryland: National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html.

Sweet, William V., Greg P. Dusek, J.T.B. Obeysekera, and John J. Marra. 2018. "Patterns and Projections of High Tide Flooding along the U.S. Coastline Using a Common Impact Threshold." 086. NOAA Technical Report NOS CO-OPS. NOAA. https://repository.library.noaa.gov/view/noaa/17403.

Teodoro, Manuel P. 2019. "Water and Sewer Affordability in the United States." *AWWA Water Science* 1 (2): e1129. https://doi.org/10.1002/aws2.1129.

Tessum, Christopher W., David A. Paolella, Sarah E. Chambliss, Joshua S. Apte, Jason D. Hill, and Julian D. Marshall. 2021. "PM2.5 Polluters Disproportionately and Systemically Affect People of Color in the United States." *Science Advances* 7 (18): eabf4491. https://doi.org/10.1126/sciadv.abf4491.

Texas Commission on Environmental Quality. 2021. "TCEQ Plan: After-Action Review of Public Water Systems and Winter Storm Uri." https://www.tceq.texas.gov/downloads/publications/gi/gi-598.pdf.

Thiem, Haley. 2023. "Former Hurricane Hilary brought Southern California its first-ever tropical storm watch." *Climate.gov*, August 21, 2023. http://www.climate.gov/news-features/event-tracker/former-hurricane-hilary-brought-southern-california-its-first-ever.

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. 2018. "Explaining Differential Vulnerability to Climate Change: A Social Science Review." *WIREs Climate Change* 10 (2). https://doi.org/10.1002/wcc.565.

Thomas, Timothy K., Jake Bell, Dana Bruden, Millie Hawley, and Michael Brubaker. 2013. "Washeteria Closures, Infectious Disease and Community Health in Rural Alaska: A Review of Clinical Data in Kivalina, Alaska." *International Journal of Circumpolar Health* 72 (1). https://doi.org/10.3402/ijch.v72i0.21233.

Thompson, Andrea. 2023. "Here Are the Stunning Heat Records Set So Far This Summer." *Scientific American*, July 27, 2023. https://www.scientificamerican.com/article/here-are-the-stunning-heat-records-set-so-far-this-summer1/.

Thompson, Vikki, Alan T. Kennedy-Asser, Emily Vosper, Y. T. Eunice Lo, Chris Huntingford, Oliver Andrews, Matthew Collins, Gabrielle C. Hegerl, and Dann Mitchell. 2022. "The 2021 Western North America Heat Wave among the Most Extreme Events Ever Recorded Globally." *Science Advances* 8 (18): eabm6860. https://doi.org/10.1126/sciadv.abm6860.

Tidwell, Vincent, Vanessa Vargas, Shannon Jones, Bern Dealy, Calvin Shaneyfelt, Braeton Smith, and Barbara Moreland. 2016. "Analysis of High Plains Resource Risk and Economic Impacts." United States. https://doi.org/10.2172/1248575.

Tran, Tiffany, Hélène Baribeau, and Laurie Sullivan. 2021. "Mitigate Wildfire Impacts on Drinking Water Quality and Operations." *Opflow* 47 (5): 10–15. https://doi.org/10.1002/opfl.1543.

Trotta, Daniel. 2022. "Jackson, Mississippi, to Go without Reliable Drinking Water Indefinitely." *Reuters*, August 30, 2022. https://www.reuters.com/world/us/floods-knock-out-drinking-water-supply-jackson-mississippi-2022-08-30/.

United Nations. n.d. "THE 17 GOALS | Sustainable Development." n.d. https://sdgs.un.org/goals#goals. Accessed June 8, 2022.

———. 1972. Report of the United Nations Conference on the Human Environment. https://www.un.org/en/conferences/environment/stockholm1972.

———. 2014. The Human Right to Water and Sanitation. 2014. https://www.un.org/waterforlifedecade/human_right_to_water.shtml.

United Nations Educational, Scientific, and Cultural Organization, UN-Water. 2020. *United Nations World Water Development Report 2020: Water and Climate Change*. UNESCO. https://digitallibrary.un.org/record/3892703#:~:text=The%202020%20edition%20of%20the,management%20offers%20in%20terms%20of.

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.

US Census Bureau. 2021. 2017-2021 American Community Survey 5-Year Estimates Selected Population Data Profiles. Table. Selected Housing Characteristics. https://data.census.gov/.

UN-Water. 2021. *Summary Progress Update 2021: SDG 6 - Water and Sanitation for All*. UN-Water. https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf.

UN-Water Expert Group on Water and Climate Change. 2019. *Climate Change and Water: UN-Water Policy Brief. UN-Water.* https://www.unwater.org/sites/default/files/app/uploads/2019/10/UN_Water_PolicyBrief_ClimateChange_Water.pdf.

US Army Corps of Engineers. 2022. "Corps Begins Constructing Underwater Sill to Halt Saltwater Intrusion in Mississippi River." New Orleans District. 2022. https://www.mvn.usace.army.mil/Media/News-Releases/Article/3185907/corps-begins-constructing-underwater-sill-to-halt-saltwater-intrusion-in-missis/.

US Climate Resilience Toolkit. 2023. Inland Flooding. U.S. Climate Resilience Toolkit. May 19, 2023. https://toolkit.climate.gov/topics/coastal-flood-risk/inland-flooding.

US Department of Homeland Security. 2022. Extreme Heat. https://www.ready.gov/heat.

US Environmental Protection Agency. 2015a. *Climate Change in the United States: Benefits of Global Action*. Risk Analysis 30-R-15–001. The Climate Change Impacts and Risk Analysis (CIRA) Project. Washington, DC, USA: US EPA Office of Atmospheric Programs - Climate Change Division. https://www.epa.gov/sites/default/files/2015-06/documents/cirareport.pdf.

———. 2015b. Protect Your Home's Water. US Environmental Protection Agency. 2015. https://www.epa.gov/privatewells/protect-your-homes-water.

———. 2015c. "Incident Action Checklist – Tornado: Water and Wastewater Utilities." EPA 817-F-15-007. US EPA, Office of Water. https://www.epa.gov/system/files/documents/2021-10/incident-action-checklist-tornado_508c-final.pdf.

———. 2015d. Information about Public Water Systems. https://www.epa.gov/dwreginfo/information-about-public-water-systems. Accessed October 12, 2023.

———. 2021a. Storm Surge Inundation Series, Story Map Series. 2021. https://www.arcgis.com/apps/MapSeries/index.html?appid=852ca645500d419e8c6761b923380663.

———. 2021b. *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. EPA 430-R-21-003. US EPA, Office of Atmospheric Programs. https://www.epa.gov/cira/social-vulnerability-report.

———. 2022. Wildfire Conditions & Risk Map for Water Utilities. ArcGIS StoryMaps. October 4, 2022. https://storymaps.arcgis.com/stories/54123fb6d09b49a49b91cbe4d64fdf66. Accessed May 23, 2023.

———. 2023a. Clean Watersheds Needs Survey. 2023. https://www.epa.gov/cwns. Accessed September 12, 2023.

———. 2023b. Climate Adaptation and Water Utility Operations. Climate Change Adaptation Resource Center. 2023. https://www.epa.gov/arc-x/climate-adaptation-and-water-utility-operations. Accessed September 25, 2023.

———. 2023c. Regional Screening Levels (RSLs) - Generic Tables. 2023. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables. Accessed September 30, 2023.

———. 2023d. *Drinking Water Infrastructure Needs Survey and Assessment: 7th Report to Congress*. US Environmental Protection Agency. https://www.epa.gov/ground-water-and-drinking-water/epas-7th-drinking-water-infrastructure-needs-survey-and-assessment.

US Environmental Protection Agency, Office of Water. 2021. Per- and Polyfluoroalkyl Substances (PFAS). November 16, 2021. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas#:~:text=On%20March%2014%2C%202023%20%2C%20EPA,known%20as%20GenX%20Chemicals)%2C%20perfluorohexane. Accessed June 28, 2023.

US Food and Drug Administration. 2022. The Microbead-Free Waters Act: FAQs. FDA. March 4, 2022. https://www.fda.gov/cosmetics/cosmetics-laws-regulations/microbead-free-waters-act-faqs.

US Geological Survey. 2019. *Saltwater Intrusion*. Water Resources Mission Area. March 2, 2019. https://www.usgs.gov/mission-areas/water-resources/science/saltwater-intrusion.

US Global Change Research Program. n.d. Heavy Precipitation. Accessed September 28, 2023a. https://www.globalchange.gov/indicators/heavy-precipitation.

———. n.d. Sea Level Rise. Accessed August 23, 2023b. https://www.globalchange.gov/indicators/sea level-rise.

Vose, J.M., D.L. Peterson, G.M. Domke, C.J. Fettig, L.A. Joyce, R.E. Keane, C.H. Luce, et al. 2018. "Forests." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, edited by D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, T.K. Maycock, B.C. Stewart, and K.L.M. Lewis, Volume II:232–67. Washington, D.C.: U.S. Global Change Research Program. https://nca2018.globalchange.gov/chapter/6/.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner. 2017. "Temperature Changes in the United States." In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Washington, D.C.: U.S. Global Change Research Program. https://science2017.globalchange.gov/chapter/6/.

Wahl, Eugene R., Eduardo Zorita, Valerie Trouet, and Alan H. Taylor. 2019. "Jet Stream Dynamics, Hydroclimate, and Fire in California from 1600 CE to Present." *Proceedings of the National Academy of Sciences* 116 (12): 5393–98. https://doi.org/10.1073/pnas.1815292116.

Wang, Dawei, Yuanyuan Chen, Mourin Jarin, and Xing Xie. 2022. "Increasingly Frequent Extreme Weather Events Urge the Development of Point-of-Use Water Treatment Systems." *Npj Clean Water* 5 (1): 1–7. https://doi.org/10.1038/s41545-022-00182-1.

Wasley, Emily, Kathy Jacobs, and Jeremy Weiss. 2020. *Mapping Climate Exposure and Climate Information Needs to Water Utility Business Functions*. The Water Research Foundation. https://www.wucaonline.org/assets/pdf/project-4729A-research-report.pdf.

WaterAid. 2021. *Equality, Inclusion and Rights Framework*. WaterAid. https://washmatters.wateraid.org/publications/equality-inclusion-and-rights-framework.

Watkins, Deborah J., Héctor Ramón Torres Zayas, Carmen M. Vélez Vega, Zaira Rosario, Michael Welton, Luis D. Agosto Arroyo, Nancy Cardona, et al. 2020. "Investigating the Impact of Hurricane Maria on an Ongoing Birth Cohort in Puerto Rico." *Population and Environment* 42 (1): 95–111. https://doi.org/10.1007/s11111-020-00345-7.

Watson, Kirk P., Renée Cross, Mark P. Jones, Gail Buttorff, Jim Granato, Pablo Pinto, Savannah L. Sipole, and Agustín Vallejo. 2021. *The Winter Storm of 2021*. Hobby School of Public Affairs, University of Houston. https://uh.edu/hobby/winter2021/storm.pdf.

WECR. Letter to Senator Tammy Duckworth and Co-chairs, Environmental Justice Caucus of the Senate. 2020. Request from EJ Caucus of Senate to Address Policy Issues, Consolidated Responses from Members of the Water Equity and Climate Resilience Caucus. January 31, 2020.

Wehner, Michael F., Jeff R. Arnold, Thomas Knutson, Kenneth E. Kunkel, and Allegra N. LeGrande. 2017. "Droughts, Floods, and Wildfire." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, edited by Donald J. Wuebbles, David W. Fahey, Kathy A. Hibbard, David J. Dokken, Brooke C. Stewart, and Thomas K. Maycock, Volume I:231–56. Washington, DC: US Global Change Research Program. https://science2017.globalchange.gov/chapter/8/.

Wehner, Michael, and Christopher Sampson. 2021. "Attributable Human-Induced Changes in the Magnitude of Flooding in the Houston, Texas Region during Hurricane Harvey." *Climatic Change* 166 (May). https://doi.org/10.1007/s10584-021-03114-z.

White, Rachel H., Sam Anderson, James F. Booth, Ginni Braich, Christina Draeger, Cuiyi Fei, Christopher D. G. Harley, et al. 2023. "The Unprecedented Pacific Northwest Heatwave of June 2021." *Nature Communications* 14 (1): 727. https://doi.org/10.1038/s41467-023-36289-3.

Whyte, Kyle. 2018. "Settler Colonialism, Ecology, and Environmental Injustice." *Environment and Society* 9 (1): 125–44. https://doi.org/10.3167/ares.2018.090109.

Whyte, Kyle, Rachael Novak, M.B Laramie, M.G Bruscato, Dominique M. David-Chavez, M.J Dockry, M.K Johnson, C.E Jones, and K Leonard. 2023. "Ch 16. Tribes and Indigenous Peoples." In *Fifth National Climate Assessment*. Washington, DC, USA: U.S. Global Change Research Program. https://nca2023.globalchange.gov/chapter/16/.

Wibbenmeyer, Matthew, Matthew R Sloggy, and José J Sánchez. 2023. "Economic Analysis of Wildfire Impacts to Water Quality: A Review." *Journal of Forestry*, April, fvad012. https://doi.org/10.1093/jofore/fvad012.

Williams, A. Park, Benjamin I. Cook, and Jason E. Smerdon. 2022. "Rapid Intensification of the Emerging Southwestern North American Megadrought in 2020–2021." *Nature Climate Change* 12 (3): 232–34. https://doi.org/10.1038/s41558-022-01290-z.

Wilson, Michael, and Hurubie Meko. 2023. "Flooding in New York: Rain Eases, but Officials Warn That Flood Risks Remain." *The New York Times*, September 29, 2023. https://www.nytimes.com/live/2023/09/29/nyregion/nyc-rain-flash-flooding.

Wing, Oliver E. J., William Lehman, Paul D. Bates, Christopher C. Sampson, Niall Quinn, Andrew M. Smith, Jeffrey C. Neal, Jeremy R. Porter, and Carolyn Kousky. 2022. "Inequitable Patterns of US Flood Risk in the Anthropocene." *Nature Climate Change* 12 (2): 156–62. https://doi.org/10.1038/s41558-021-01265-6.

Winter, Mary, and Cliff Foster. 2014. "Ogallala Aquifer – Lifeblood of the High Plains. Part I: Withdrawals Exceed Recharge." CoBank Knowledge Exchange.

Writer, Jeffrey H., Amanda Hohner, Jill Oropeza, Amanda Schmidt, Kaelin M. Cawley, and Fernando L. Rosario-Ortiz. 2014. "Water Treatment Implications after the High Park Wildfire, Colorado." *Journal AWWA* 106 (4): E189–99. https://doi.org/10.5942/jawwa.2014.106.0055.

Wuebbles, Donald J., D.R. Easterling, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, et al. 2017. "Our Globally Changing Climate." In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, pp.35-72. Washington, D.C.: U.S. Global Change Research Program. https://science2017.globalchange.gov/chapter/1/.

Yin, Changyan, Jiayi Wang, Xin Yu, Yong Li, Denghua Yan, and Shengqi Jian. 2022. "Definition of Extreme Rainfall Events and Design of Rainfall Based on the Copula Function." *Water Resources Management* 36 (August): 3759–78. https://doi.org/10.1007/s11269-022-03229-7.

Yuill, Brendan, Gary L. Brown, Eden Krolopp, Hailey Laurent, and David Ramirez. 2023. “Dynamics of the Saltwater Wedge in the Lowermost Mississippi River during the 2022 Low Flow Season.” In *Poster Presentations*. St. Lous, MO. https://www.sedhyd.org/2023Program/1/323.pdf.

Zamyadi, Arash, Sherri L. MacLeod, Yan Fan, Natasha McQuaid, Sarah Dorner, Sébastien Sauvé, and Michèle Prévost. 2012. “Toxic Cyanobacterial Breakthrough and Accumulation in a Drinking Water Plant: A Monitoring and Treatment Challenge.” *Water Research*, Cyanobacteria: Impacts of climate change on occurrence, toxicity and water quality management, 46 (5): 1511–23. https://doi.org/10.1016/j.watres.2011.11.012.

Zhuang, Yizhou, Rong Fu, Benjamin D. Santer, Robert E. Dickinson, and Alex Hall. 2021. “Quantifying Contributions of Natural Variability and Anthropogenic Forcings on Increased Fire Weather Risk over the Western United States.” *Proceedings of the National Academy of Sciences* 118 (45): e2111875118. https://doi.org/10.1073/pnas.2111875118.

PACIFIC INSTITUTE
REIMAGINING WATER FOR A CHANGING WORLD

pacinst.org