EARLY CHILDHOOD SCIENTIFIC COUNCIL ON EQUITY AND THE ENVIRONMENT

A Cascade of Impacts: The Many Ways Water Affects Child Development

WORKING PAPER 2

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Water is Essential for Life

This working paper is the second in a series focusing on the ways that environmental conditions shape young children's development. Water is just one component of a set of interrelated conditions that affect how children's bodies and brains develop. This working paper offers a summary of current knowledge about how water impacts developing biological systems.

Water comprises around 60% of the adult human body and 75% of infants' bodies.[1] The brain, heart, kidney, and lungs are all more than three-quarters water and require continued hydration to function.[2] Our bodies need water to dissolve food, absorb nutrients, dissipate heat, distribute blood, wash waste from our system, lubricate and cushion joints, and protect our brains from physical shocks.[1,3,4] Children drink more water per pound of body weight than adults. Infants consume the most water of any age group, whether through formula prepared with water or through breast milk, which also contains water.[5]

Because our bodies need a near-constant supply of water, its availability and quality are critical parts of the environment that shape child development. What surrounds us—and goes into us—shapes our biology, including our brain, immune, and metabolic systems. This is particularly true during the prenatal and early childhood periods when our bodies are especially sensitive to outside influences. This developmental environment—the full range of experiences and exposures that children have in the places where they live, learn, grow, and play—can fuel healthy development through access to good nutrition, relationships, resources, and opportunities, or it can derail healthy development when it includes sources of significant adversity, such as air pollution, unsafe housing, or lack of economic opportunity.[6] The policy-, system-, and program-level decisions that shape the environment for young children and pregnant people can have a long-term, positive impact on children's cognitive development as well as lifelong physical and mental health by ensuring reliable access to safe, clean water. Even if children have already been exposed to contaminants, policies and programs can mitigate potential harm by helping caregivers provide supportive, stable environments and good nutrition during early development.[7]

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Due to extended droughts, large-scale farming of water-hungry plants in arid climates, populations using more water than their local sources can naturally replenish, and toxic contamination, freshwater supplies are increasingly endangered. California's Central Valley is just one of the world's 21 largest aquifers (areas where water naturally collects underground) that are shrinking.[8] At the same time, climate change is worsening droughts and floods, which further threaten freshwater supplies.

Warmer temperatures increase the rate of water's evaporation, which has two effects. First, evaporation further heats the air, making droughts more common in parts of western North America as well as other regions of the world. And, because more evaporation puts more water vapor into the air, storms become more intense when they do happen. The increased frequency and intensity of "atmospheric rivers"—which caused extensive flooding in California in early 2024—are good examples of global climate change boosting moisture in the atmosphere, with extreme and potentially catastrophic consequences.[9] In addition to destroying buildings and roads, more severe storms can lead to floods that overwhelm the infrastructure we depend on to treat and manage our drinking water. Heavier rains also wash more pollutants (for example, oil from roads and waste from agriculture) into our lakes, rivers, and aquifers.[10]

While often forgotten and unseen, the infrastructure that brings us drinking water is essential not only to every person's health but also to every community's quality of life and economic development. Without these water systems, businesses, schools, restaurants, and hospitals would fail.[11] Beyond drinking, we use fresh water for hygiene, growing and cooking food, waste disposal, cooling power sources, and a wide range of recreational activities.[12] Investments in the effectiveness and resilience of our water systems determine whether people of all ages have consistent, affordable access to safe water.[13]

Without a constitutional right to water, historical disputes over property rights, town borders, and dispossession of Native lands have resulted in significantly less access to affordable, clean water in Indigenous communities, disenfranchised rural areas, and minoritized populations.

In the US, these systems were once widely presumed to produce nearly universal, clean, affordable, and trustworthy water, but, in truth, there are serious gaps and challenges.[14] Without a constitutional right to water, historical disputes over property rights, town borders, and dispossession of Native lands have resulted in significantly less access to affordable, clean water in Indigenous communities, disenfranchised rural areas, and minoritized populations. For example, unincorporated communities in South Texas originally developed to house farmworkers from Mexico and Central America were denied the right to vote on water governance in the 1970s, leading to situations today where residents depend on water trucks, stores, and vending machines for water.[14] As a result of discriminatory zoning and disinvestment in communities where people of color live, including practices such as redlining, Black or Latin American households are nearly twice as likely to be without functional access to clean water than White households.[15] Black and Hispanic populations are also more likely to spend more days evacuated as a result of hurricanes and floods, to be without power or heat, and to suffer longer disruptions to their health care.[16]

All of these inequities are the result of decisions that we have made as communities, states, and a nation. New decisions can reverse outdated prejudices and provide all people with access to clean drinking water, with profound effects on the health and well-being of our children. In addition to federally supported upgrades to water systems and regulatory protections, communities across the US are implementing a wide range of practical solutions to improve the quality and availability of water, from advanced testing and filtration to green technologies and adaptations that make our streets, buildings, and systems more resilient to storms and floods.[17] As with any complex issue, understanding the full scope of how our water is affecting us—particularly children—is a critical first step in coming together to solve the problems we face.

How Water Affects Children's Health, Learning, and Behavior

A young child's organs are developing rapidly, so they require more water than adult organs and are more sensitive to what is in that water. These organs absorb everything that is in the water we drink, from beneficial nutrients and bacteria to toxic metals, chemicals, viruses, and parasites. Many chemicals can even cross through the placenta to affect a fetus.[18,19] This has lasting implications for children's development. Infants, young children, and pregnant people also become dehydrated more quickly and experience unique consequences from dehydration.[20] For example, dehydration during pregnancy can contribute to decreased fetal weight and length.[21]

Adults need clean water for good health, and a person who is healthy at the time of conception is more likely to have a healthy pregnancy and baby.[22] Consistent access to clean water, along with health, nutrition, hygiene, and psychosocial care for adults before they conceive a child, has been shown to improve birth outcomes and early childhood development.[23] Conversely, water is one of the primary ways in which people are exposed to hormone-disrupting chemicals, and exposure of either biological parent before conception has been linked to a reduced ability to become pregnant and reduced birthweight in their babies.[24] Maternal exposure to these chemicals can also increase inflammation and oxidative stress (a chemical imbalance that damages cells),[25] which can lead to preterm birth, reduced fetal growth, and altered brain development in their baby.[26,27] Paternal exposures to toxic chemicals before conception may even change the chemical markers on genes in sperm that affect the growth of a fetus[24] and increase the risk of birth defects and diseases in the child after birth, including neurodevelopmental and metabolic disorders.[28] Preconception exposures in both parents can result in a "cocktail effect," in which the combination creates a higher potential for negative outcomes than the two exposures would separately.[24]

Access to clean water across the lifespan significantly reduces these effects, but water contaminants are just one of many ways in which water affects development. A range of disruptions in the availability and quality of water can affect child development through multiple pathways, including the brain, the immune system, gene expression, and nutrition.

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Brain development—To function properly, the brain needs adequate water and nutrients. Children's attention and memory can be impaired by even mild dehydration and can improve when water is provided.[29] During early development, as the foundations of the brain's architecture are being built, brain cells called neurons are highly plastic (easy to change), numerous (in the billions), and mobile (migrating to their ultimate location). Neurotoxicants in drinking water disrupt the hormones and proteins that drive the construction of brain architecture, which negatively affects all 3 attributes—the plasticity, number, and mobility of neurons—as well as the formation of efficient connections between brain cells.[5] The brain is typically protected from many toxic chemicals by a protective membrane that regulates the flow of chemicals into and out of the brain.[30] However, this membrane is not fully developed before birth or in infancy, so contaminants are more likely to cross into the brain during this sensitive period, with lifelong impacts.[13]

Specific drinking water contaminants can have different effects on developing brains depending on when, how long, how much, and how frequently they enter the body. For example, nitrates have been found to have adverse health effects for infants whose mother's water supply contains levels of nitrates above the US safety level, which is more likely in private wells.[31] Even low doses of lead in drinking water have long been associated with behavioral and cognitive impairments, and higher doses cause greater damage, particularly in infants and young children.[32] High levels of arsenic are associated with a neuronal protein linked to Parkinson's disease, as well as damage from inflammation and oxidative stress.[33]

Children's brain development and mental health can also be affected when there is too much or too little water in the environment around them, such as during flooding or drought. For example, there are documented increases in anxiety, depression, and post-traumatic stress disorder (PTSD)—some of which last for more than a decade[34]—from experiencing a destructive flood and its subsequent traumas, such as the loss of a home or loved one, forced relocation, and unstable access to water or food.[35,36] Multiple studies have found that children born to adults who were pregnant at the time of a natural disaster showed marked differences in temperament, mood, behavior, and motor development than those who were not exposed.[37] After 2017's Hurricane Irma, which displaced 6 million people in Florida, 9- and 10-year-old children who had lived through the event subsequently had fewer cells in the hippocampus (the part of the brain related to memory) and performed significantly worse on memory tests than children from the same region who were tested before the hurricane. Researchers theorize that a heightened focus on new information during an uncontrollable natural disaster may facilitate a quick response or evacuation, but the enduring changes in developing brains can reduce long-term memory, a critical ability for school success.[38]

Infections and the immune system—Because floods can overwhelm sewage systems and industrial areas, they often put a wide range of viruses, bacteria, and other pathogens into direct contact with children, resulting in ear infections, noroviruses, and gastrointestinal problems.[36] For example, flooding from Hurricane Harvey in 2017 released "a toxic mix of chemicals, sewage, biohazards, and 8 million cubic yards of garbage" across Houston, Texas, according to the CDC.[39] Over the following 2 weeks, nearby emergency departments experienced a 200% increase in visits each day, many for gastrointestinal illness, nausea, vomiting, and diarrhea, more than a quarter of which were children.[39] Disaster planning that coordinates health care responses within a few hours' driving distance can help hospitals prepare for this type of medical surge,[39] and improving the flood resilience of buildings, infrastructure, and water systems, as New York City has done, is an effective, preventative approach.[40]

In addition, exposure to certain chemicals in drinking water (prenatally or in early childhood) can suppress the developing immune system's production of antibodies. This puts children at greater risk for infectious diseases, allergies, and asthma and can inhibit the body's response to vaccinations that protect against diseases such as diphtheria, tetanus, and rubella.[41] Other chemicals can disrupt the neuroendocrine system, which regulates hormones that play critical roles in fighting disease. Water contaminants also increase the risk of kidney and liver dysfunction, impairing the ability of those organs to help fight infection and disease by filtering and detoxifying elements in the body.[30] Finally, numerous water contaminants have been found to increase inflammation, which is a core part of the immune response.[30,33] Chronic inflammation puts substances designed to attack invading viruses and clear out tissue damage into constant contact with healthy organs. This can lead to a wide range of diseases, including cardiovascular disease, diabetes, asthma, some thyroid conditions, and even depression and dementia.[42] Understanding these outcomes underscores the multitude of health benefits that would accrue from more effective and consistent regulation, testing, and treatment of drinking water.[43,44]

Gene expression—During early development, our bodies respond to the experiences and exposures we have by leaving chemical "tags" on genes. The signature pattern of these tags, known as the "epigenome," can activate, suppress, or silence the expression of a gene. This interaction between genes and the environment lies at the intersection of human health and disease. Exposure to contaminants early in the development of the central nervous system can result in these tags being added to DNA during egg or sperm formation. Epigenetic tags usually stay in place for the life of the individual and can even persist across generations.[33,45] While they may not result in immediate changes, when aging processes interact with these early genetic modifications, the result is a greater risk of disease. For example, prenatal exposure to lead alters the regulation of genes that are related to specific proteins that have been associated with Alzheimer's disease.[46] High levels of arsenic in maternal blood are associated with changes in the encoding and expression of genes that are linked to worse birth outcomes (e.g., preterm birth) and long-term health (e.g., higher mortality and cancer).[47] There is also evidence that experiencing trauma early in life—for example, displacement, destruction of property, or family death caused by a flood or extreme drought—can alter gene expression in a way that compounds stresses experienced later in life and worsens the risk of a child developing subsequent psychiatric disorders, including PTSD.[48]

Nutrition—Reliable access to water in sufficient quantity and quality is critical for growing, washing, and cooking nutritious foods. Water affects not only the viability of crops but also the nutritional value of our food, whether it is grown in or outside the US. Around 60-70% of freshwater worldwide is used for agriculture.[49] Irrigating crops with contaminated water can lead to contaminated food products, which can cause illness when eaten.[50] In addition, lower levels of nutrients were found in crops such as wheat, barley, legumes, and vegetables after either floods or droughts.[51] Drought, in particular, reduces wheat crop yields and also alters its protein content.[52] Thus, both drought and flooding can lead to decreased crop production and nutritional value. As a result, children in the US and around the world are at greater risk of not having affordable access to the high-nutritional-value food they need for healthy development.

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In the body, water is critical for digesting, absorbing, transporting, and metabolizing nutrients. Infants are particularly sensitive, as they receive most of their nutrition through water-based liquids, such as breast milk and formula. Lactating caregivers exposed to heavy metals through drinking water have higher circulating blood concentrations of these toxic compounds, which can enter breast milk. Infant formula and other foods prepared with contaminated water can also expose infants to pathogens or harmful chemicals. School-age children are also affected by real and perceived barriers to accessing water. If water in schools is of poor quality or is not trusted, students tend to avoid drinking it and instead may opt for readily available sugar-sweetened beverages.

This can worsen disparities in obesity and diabetes between high-income groups with access to high-quality water and low-income groups without it.[13]

Nutrition can play an important role in reducing the likelihood that children who have been exposed to contaminants will experience negative outcomes. For example, animal studies suggest that lycopene, an antioxidant found in tomatoes and other foods, may protect against the toxic effects of mercury exposure.[53] Human research indicates that iron may reduce the concentration of lead in the blood[54] and that higher levels of folate, a nutrient found in dark green leafy vegetables, beans, eggs, and other foods, are associated with lower levels of arsenic in the blood.[55]

How We Get Our Water

Americans get water for drinking, cooking, bathing, and sanitation from a variety of sources. According to the CDC, 82% of Americans get their water through just 8% of the country's community water systems—the large water systems in major metropolitan areas. But there are more than 150,000 public water systems in the US; the rest are a mixture of small community systems, individual wells, and privately owned systems like those at mobile home parks, campgrounds, migrant labor camps, and some large offices or hospitals. Where no system is available, water trucks, service stations, and stores selling bottled water fill the gaps.[56]

Whether or not American families have access to safe drinking water is determined by where we live and how much political and economic power we have to demand it.

A recent string of serious incidents is eroding trust in our water systems. In 2014, 100,000 residents in Flint, Michigan, found elevated levels of lead in their drinking water after authorities switched water sources as a cost-saving measure.[14] In 2022, more than 150,000 residents in Jackson, Mississippi, had no safe drinking water for weeks when flooding contaminated the water supply.[57] Rural areas are also affected. During 2022, the state of Texas issued nearly 2,500 boil-water notices—the majority in small rural communities—mostly due to maintenance issues and leaking in aging water systems that can result in contamination.[58] These costly repair-and-replace situations tend to arise after decades of underinvestment despite the warnings and concerns voiced by local residents.[59] Further, analyses of water utilities nationally demonstrate that these are not isolated situations where predominantly Black communities received poor-quality water; rather, they reflect widespread systemic issues serving low-income communities with higher populations of Black and Hispanic residents.[60]

Whether or not American families have access to safe drinking water is determined by where we live and how much political and economic power we have to demand it.[15] Despite the high-profile failures of large systems like Flint and Jackson, smaller systems tend to fail more often than larger ones. Individual private wells (which are largely unregulated) are also prone to water shortages and contamination. Residents of mobile-home parks have consistently worse water quality and reliability than those living in more permanent housing.[14] Each type of system is monitored differently (or not at all) for safety, and responsibility is scattered across jurisdictional hierarchies of international, federal, state, local, and tribal governments.[14]

Mismatched utility districts, municipal boundaries, and historical exclusionary policies can result in a community or neighborhood being excluded from a nearby network.[14] American Indian/Native Alaskan households are especially likely to be separated from water systems; in Arizona, Navajo and Apache households are 13 times more likely to have incomplete plumbing than White households. As one example, looking behind the statistics, an Arizona mother living on the Navajo reservation without access to a public water system must stretch a water delivery of 400 gallons per month for her family, compared with the average per capita American consumption of 100 gallons per day.[61] As another example, in Apex, North Carolina, side-by-side neighborhoods had starkly different access to water. While Apex overall is 74% White, the Irongate Drive neighborhood is 79% Black. Because of districting decisions made after the Civil War, homes in the Irongate neighborhood were not granted access to Apex's public water services. Instead, they relied on private wells. In the early 2000s, nearly 80% of these wells were running dry and showed signs of bacterial contamination. It was not until 2020, with support from local universities and civil rights attorneys, that the neighborhood was finally connected to the town's water system.[15]

Where there are water systems, many were built 100 or more years ago and are no longer sufficient for our needs, particularly in light of the increased number and severity of extreme weather events.[62] The National Climate Assessment 2023 reports, "There 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."[63] Yet, our systems are mostly unprepared and outdated. The American Society of Civil Engineers gives America's drinking water infrastructure a "C-" grade, in part because the federal government's share of overall investment in water infrastructure fell from 63% in 1977 to 9% in 2017, leading to chronic disinvestment in maintaining and upgrading the systems. Still, the association also notes signs of progress, with federal financing programs for water expanding since 2021 and water utilities reinvesting in their networks. For example, Tampa, Cleveland, and Philadelphia are among the cities using millions of dollars from the 2021 Bipartisan Infrastructure Law to replace or improve their water systems.[64]

As one example of how these investments pay off, 2 years after a water treatment plant in Greenville, North Carolina, flooded in 1999's Hurricane Floyd, the Economic Development Administration gave the city $4.8 million to improve its facility's flood protection. When Hurricane Matthew flooded the region in 2016, the water treatment plant survived and saved Greenville over $150 million in damage—31 times as much as the cost to protect it.[65] The National Climate Assessment, meanwhile, reports that in 2023, the US experienced 28 extreme weather or climate disasters whose damages cost more than $1 billion each, costing the nation nearly $93 billion in total.

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The Clean Water Act (CWA) of 1972 and the Safe Drinking Water Act (SDWA) of 1974 established drinking water standards for a number of pollutants. These standards dramatically improved drinking water quality until they were weakened by federal officials during the 2016-2020 administration, imperiling the safety of the water consumed by millions of Americans.[66] During this time, violations of the CWA and SDWA were rampant—and unevenly distributed. Across the country, a coalition of researchers and advocates documented more than 170,000 violations between 2016 and 2019, affecting water systems serving 130 million people (nearly 40% of the US population).[67] These researchers also found a "disturbing relationship between multiple sociodemographic characteristics—especially race—and drinking water violations." Systems serving communities that have been historically marginalized according to race, ethnicity, or language spoken were found to have more violations of contaminants laws and less likely to have these violations corrected.[67] The most serious, repeated violations are highly clustered by geography, mostly in rural areas in Appalachia, New Mexico, Alaska, Puerto Rico, and the upper Midwest, Northwestern mountains, and lower Mississippi regions.[59] Full, fair enforcement of these critical public health standards, along with financial support for fixing systems that fail to meet the standards, remains an important goal of any policy solution.

Large- and small-scale systems typically treat water near the source with a multi-step process that includes chemicals such as chlorine to kill bacteria-borne diseases like cholera and typhoid. Water is treated differently depending on the source. For example, water from lakes, rivers, and streams typically contains more sediment, germs, chemicals, and toxins than water that comes from deep underground and therefore requires more treatment.[68] The type and effectiveness of water treatment varies from system to system,[64] and many harmful contaminants remain unregulated,[14] so the water leaving each treatment facility is of variable quality. After treatment, the plants send water through pipes to people's homes (although more than a million Americans do not have access to piped water).[14] Wells also deliver water, often untreated, through pipes into homes.

These pipes can be part of the problem—and part of the solution. Pipes made of lead were banned in 1986, but over 9 million lead pipes installed in the late 1800s to early 1900s continue to service US homes and schools.[44] Lead solder used to join copper, brass, and bronze pipes was present in 98% of US homes before 1986, and lead continues to be common in plumbing components, including faucets, galvanized steel pipe coatings, valves, and meters.[44] Water corrodes lead, leaching it into the system and damaging system components. Yet replacing lead pipes and fixtures is not only possible but also cost-effective. Flint Lead Free, a multi-sector community-based group aimed at eliminating lead exposure in Flint, Michigan, has replaced more than 14,000 lead pipe water service lines to homes since 2017 and projects that the future economic benefits to the community from the replacements will reach over $200 billion.[69] A 2023 national cost-benefit analysis found that savings from reduced corrosion damage to water infrastructure and appliances alone would balance the cost of replacing lead and copper pipes, with billions in health and learning benefits on top.[44]

Shifting efforts from responding to water crises to preventing them is particularly important. The Flint Registry, the nonprofit in which Flint Lead Free is under, has served over 20,000 people by making over 30,000 connections to programs and services that promote health and wellness.[69] Michigan recently revised its Lead and Copper Rule, which would take inventory of existing water services lines by 2025 and require all lead pipes to be replaced by 2041. This would result in net savings of over $1.9 billion and reduce lead exposure for over 400,000 children. Over 25% of these children (106,900 children) would be in households below 100% of the federal poverty level and 36% non-White (19% being Black or African-American), highlighting the tangible benefit of reducing health disparities.[70] The recent EPA proposal to update the National Lead and Copper Rule takes even more stringent measures; these changes would require all lead pipes to be replaced over the next 10 years and lower the level at which elevated lead is addressed, a major public health victory.[71] Importantly, regulations such as these shift the policy focus from a reactive to a preventive stance, helping to ensure that, going forward, we can avoid drinking water crises rather than responding to them when they occur.

Protecting Children from Water Contaminants

Toxic metals such as lead are only one pathway through which water affects child development. Contaminants get into our water in a variety of ways: corrosion in our pipes, leaching of agricultural and industrial waste into groundwater, manufacturing and disposal of household products, including everything from cosmetics to furniture, overflow from floods, and inadequate testing and filtration. Children, particularly those who are very young, are especially sensitive because they consume more water per body weight and their affected organ systems are still developing. Schools and childcare facilities, where oversight and testing for contaminants in drinking water have historically been left to the states, are particularly at risk. For example, the concentration of lead in water is strongly related to how long the water has been stagnant; in schools, water can sit in pipes overnight and longer on weekends and vacations.[44] In public water systems, the EPA currently regulates about 100 of the most common contaminants, but tens of thousands of others exist and are not regulated.[44] Here, we discuss 3 of the most prominent and well-studied categories. Practical solutions exist for each of these categories in the form of testing, filtration, replacement of water system components, enactment and enforcement of strict regulations, and support for affected families.

1. Toxic Metals

- **Lead** is perhaps the best-known and most-studied heavy metal toxicant found in drinking water, partly due to the well-known crisis in Flint and partly because it is so prevalent across the US. Discoveries of elevated lead levels in drinking water have also shut down public water supplies in Washington, DC; Newark, New Jersey; Buffalo, New York; Detroit and Benton Harbor, Michigan; and more. A 2016 Reuters investigation found nearly 3,300 areas where rates of lead in children's blood were more than double those in Flint. Further, researchers estimated that more than nine million Americans who use private wells, which are unregulated and serve 15% of the US, may have unsafe levels of lead in their water.[72] Nationwide, the rate of non-Hispanic Black children with blood lead levels exceeding the CDC's recommended safe level is double that of non-Hispanic White children.[73] Lead is associated with health problems across virtually all body systems, including nervous, cardiovascular, immune, blood, kidney and liver, and reproductive/developmental systems. There is no safe level of lead in the blood; it has been classified as a probable human carcinogen by the EPA since 1988. Exposure during pregnancy affects both the health of the pregnant person and the infant's brain development and is associated with miscarriage, stillbirth, and preterm labor.[5] Only 10% of schools nationwide are required to comply with the EPA's standards for water lead levels,[5] yet even low lead levels are associated with lower cognitive performance in children, including the inability to pay attention, slowed growth and learning, and persistence of behavioral issues.[32,33]

- **Arsenic**, a known carcinogen, has been detected in more than half of US community water systems; approximately 13 million people are exposed to drinking water that exceeds the US standard.[74] Arsenic can also be found in baby foods that use rice grown in arsenic-contaminated water and soil, although the levels at which babies are at significant risk—and which manufacturers must stay beneath—continue to be debated.[75] In addition to many types of cancer, chronic exposure to arsenic is also associated with respiratory disease, cardiovascular disease, adverse birth outcomes, metabolic disorders, diabetes, immune system impairment, kidney disease, and deficits in attention, working memory, cognitive flexibility, and risk-taking behavior.[44,76] One study examining the effects of high levels of arsenic in 3 Maine school districts whose homes use private wells found that children with higher blood levels of arsenic also demonstrated lower scores on tests of memory, reasoning, and comprehension.[74] Arsenic occurs naturally as a trace component in many rocks and sediments; whether it is released into groundwater depends on local geo- and bio-chemical conditions. Arsenic also can be introduced by mining, industry, animal feed, treated lumber, and pesticides.[77] Waste from mining is a particularly abundant source of arsenic in the Southwest and Great Plains regions, especially near Indigenous communities. Fracking and coal-fired power plants also contribute to increased levels of arsenic in some areas.[78] As with lead, marginalized populations are at significantly greater risk of arsenic poisoning. Long histories of locating mining and industrial operations near low-income communities, particularly those populated by American Indian, Black, and Hispanic people, as well as the historical exclusion of these communities from publicly supported water systems, have contributed to today's disparities.[44]

Solutions: In late 2023, after decades of federal disinvestment, the EPA proposed replacing all the nation's lead pipes within 10 years,[79] funded in part by the Bipartisan Infrastructure Law of 2021.[80] Public support is essential for this proposal to be formally adopted and implemented. In 2021, the CDC lowered the action level for lead levels, triggering when public health investigations occur and when families can access special services.[81] Given the potential negative effects on fetal development when exposure occurs during pregnancy, the CDC also established guidelines for lead screening during pregnancy, with follow-up recommended when maternal lead levels reach 5 micrograms per deciliter or higher. Finally, appropriately screening children for lead in their blood is essential for connecting them to appropriate follow-up services. The American Academy of Pediatrics recommends performing a risk assessment for all children at well visits at 6 months, 9 months, 12 months, 18 months, 24 months, and yearly between ages 3 and 6, with children who are then identified as at-risk being screened with a blood lead level. Recommendations also include targeted screening for those with risk factors for high lead levels, including those living in older housing, those who are adopted, have immigrated to the US, or are refugees. In some states, Medicaid requires BLL screening in children at ages 1 and 2, but states show wide variation in screening rates.[82] For example, in 2014, South Carolina screened only 5% of eligible children.[83] A handful of states require proof of BLL screening for school enrollment, which has resulted in higher screening.[84] *Universal risk assessment for children in at-risk age groups and removal of all lead pipes and fixtures as rapidly as possible are critical pieces of a national strategy to protect all children from the damage caused by toxic exposure to lead.*

Arsenic has long been a source of concern in food products and water sources. Between 2006 and 2011, EPA regulations and federal funding enabled public water systems to reduce arsenic concentrations by 17% overall. The largest reductions occurred for Mexican-American residents (36%) and for community water systems that already had high arsenic concentrations, including those serving New England (37%) and Alaska and Hawaii (24%).[44] Unfortunately, these regulations did not extend to private well users.[85] Significant socioeconomic disparities in well testing and treatment exist in the US—largely due to cost, testing being conducted infrequently, and treatment systems in individual households are often poorly maintained.[86] Once detected, a range of treatment options for removing arsenic from drinking water is available, including some that are effective and affordable for small systems.[87] *Federal funding for arsenic* *testing and treatment should be continued for public water sources and expanded to include private well owners. Efforts to eliminate the leaching of arsenic into water sources from mining, fracking, and coal-fired power plants must be strengthened.*

2. Plastics and Forever Chemicals

- **PFAS** is the acronym for per- and polyfluoroalkyl substances, a large class of contaminants made up of more than 14,000 specific chemical compounds. While PFAS have existed since the 1940s, and questions about their toxicity were first raised in the 1960s, they are just beginning to receive significant attention.[88] PFAS are known as "forever chemicals" because they do not degrade easily and accumulate in the blood for years—even decades. They are widely used in consumer goods, such as stain-resistant carpets, grease-resistant papers (e.g., fast food containers/wrappers, microwave popcorn bags, pizza boxes), clothing, dental floss, cosmetics, paints, nonstick cookware, and fire-resistant foams used by the military and firefighters. Proximity to industrial sites involved in the manufacture of these products and waste disposal sites have been linked to higher levels of PFAS in drinking water. The contamination of crops (as well as beef and milk) is widespread as a result of farms fertilizing with sewage sludge from wastewater treatment plants, which was marketed and sold as safe and low-cost.[89]

  Drinking water is likely the largest source of PFAS exposure in the US, and formula-fed infants are thought to be the most highly exposed.[88] Higher levels of certain PFAS in the blood are associated with a greater risk of reproductive issues, developmental delays, certain cancers, weakening of the immune system, and disruption of the endocrine system. PFAS bind to fatty tissues in the body, which leads to higher concentrations in the lungs, liver, kidney, brain, and placenta. Exposure to certain PFAS during pregnancy may disrupt the growth of the placenta and increase susceptibility for later obesity, diabetes, and liver disease in the child.[88] PFAS disrupt the brain's delicate chemical balance and incapacitate specific neurotransmitters that process signals between cells, particularly in brain regions that regulate learning, memory, and anxiety.[30] Exposure to PFAS is nearly universal for people born after 1950,[88] yet what levels in the blood, if any, might be considered safe is a subject of active debate due to the sheer number and complexity of the compounds, levels, timing, sources, and combinations of exposures. In short, we know that PFAS compounds are toxic, but we don't yet fully understand how they interact with each other and what levels, if any, are safe for young children.[30]

- **Plasticizers** are a class of chemicals that are used to make materials more durable, including phthalates, polychlorinated biphenyls (PCBs), and bisphenol A (BPA). When ingested, they affect the functioning of the body's endocrine system, which consists of multiple organs and glands that orchestrate the release of hormones that keep our bodies functioning optimally. Due to their ubiquity in the environment, human exposure to plasticizers, which break down into microplastics, is virtually unavoidable.[90,91] Phthalates can leach into food and water through containers made with plasticizers, they can cross the placenta to reach fetuses, and infants can be exposed through breast milk, formula, and sucking on toys made with them.[90] These chemicals can attach themselves to a range of hormones involved in sexual development and reproduction, so researchers are particularly concerned about their effects on the human reproductive system. They can affect growth in infancy, obesity during childhood, genital development, and puberty onset. Puberty, a complex process controlled by several hormones, can be either delayed or accelerated depending on when and how much a child is exposed to these chemicals. Both pre- and post-natal exposure can lead to premature failure of the ovaries (before age 40), prolong or shorten pregnancies, and lead to cancer of the reproductive organs. Similar exposures can affect the function of testicles and lead to a broad spectrum of male reproductive disorders.[92] Many phthalates are banned and restricted in multiple countries, and healthier alternatives exist, but the long life and abundance of plastics mean that continued testing and vigilance are needed.

Solutions: Addressing contamination from plastics and forever chemicals will require limiting phthalate and PFAS manufacturing to avoid new variations, better and more widespread testing of water sources, and developing safe ways to degrade the compounds.[44] Industry representatives and their supporters have argued that toxicity data and health assessments must be researched for each of the 14,000+ PFAS compounds, a class that continues to grow in size daily.[44] It is practically and financially impossible to rigorously study every compound individually, and incalculable harm would come to people while we wait. Enough is known about the substantial health risks of the entire class to warrant caution—for example, requiring proof that chemicals in this class do not entail health risks rather than definitive proof that they do. In April 2024, the EPA issued the first national, legally enforceable drinking water standard for 6 PFAS, including 2 of the most common compounds. This is an important step forward, but a broader approach is needed in regulating such a large class of compounds if we are to protect communities from exposure. *PFAS chemical compounds must be regulated as a class, not as individual compounds, and the same is true for plasticizers. Attention must be focused on products most likely to expose infants, children, and pregnant people to these chemicals, such as crib mattress protectors, bibs,[93] food packaging, products for pregnant or lactating caregivers, and products likely to be sucked or ingested by infants, children, and adolescents.*[90]

3. Pesticides and Agricultural Runoff

- **Nitrate** levels in water resources have increased around the world from applications of inorganic fertilizer and animal manure in agricultural areas. Septic systems that do not effectively remove nitrogen, discharge from wastewater treatment plants, and fertilizer use on lawns, golf courses, and parks also increase nitrate levels in water. Private wells typically have higher nitrate concentrations than community water systems due to their shallower depth.[44] In the US, high nitrate concentrations in drinking water are most likely to be found in water used by migrant farm worker communities, in Alaskan Native villages and other tribal lands, and in disenfranchised villages along the US-Mexico border.[44] These villages, known as colonias, were created by developers who were not required to supply water systems. They were built to cheaply house legal migrants from Mexico and Central America to supply inexpensive labor to the farming industry in the 1940s-1980s. Today, as many as 1 million people live in colonias in 4 US states, and they still experience the legacy of their exclusion with high rates of poor water access and quality.[94] Nitrate ingested in water forms cancer-causing chemical compounds in the body—especially in the absence of a diet rich in fresh fruits, vegetables, and legumes (such as lentils, chickpeas, and other beans), which contain antioxidants that promote a health-protecting process in our bodies and inhibit the formation of these compounds.[44] Without these kinds of foods, which may be very difficult to find in communities that have faced decades of disinvestment in food infrastructure, nitrate-induced compounds may be more likely to cause birth defects as well as cancers of the colorectal system, bladder, kidney, ovaries, and brain.[44] In young infants, formula that is prepared with well water that contains high levels of nitrates can lead to a dangerous condition known as methemoglobinemia. This condition leads to difficulty with carrying oxygen in the bloodstream.[95] Some states provide subsidized water test kits to well owners, but well users are often unaware of the resources available to them, and state-level regulation of private wells varies dramatically across the country.[44] In the majority of states, owners are not required to test well water for safety after the well is constructed, and the protections offered by the Safe Water Drinking Act do not apply to the 23 million US households that get their drinking water from private wells. [95,96]

- **Pesticides** designed to kill insects, weeds, and fungi are widely used in homes, agriculture, schools, and parks, where they run off into streams and seep into groundwater. Heavy rains and floods increase the spread of these chemicals into water systems, where they may not be removed by conventional water treatment technologies. Despite the benefits of pesticides in protecting crops or limiting pests in parks, they pose a number of human health risks because they can accumulate in human cell membranes and interrupt key body functions.[97] Effects of exposure can include suppression of the immune system, neurological disorders such as Parkinson's disease, reproductive problems, birth defects, and cancer.[97] One particular class of pesticide, called organophosphates, attacks the nervous system of insects by blocking the ability of neurotransmitters to send signals between brain cells—and these chemicals can affect this same mechanism in humans.[98] Neurodevelopmental effects in children include abnormal reflexes in newborn infants, delayed mental and psychomotor development, and behavior disorders such as attention deficit hyperactivity disorder.[99] One particularly notorious organophosphate, trichloroethylene (known as TCE), is found in half of the 1300 most toxic US Superfund sites— abandoned properties where the EPA has designated funds to clean up hazardous waste—and has been linked to liver cancer, kidney cancer, non-Hodgkin's lymphoma, and prostate cancer in nearby residents.[100]

Solutions: The US has adopted a range of guidelines for pesticides and nitrates, and new treatment technologies that remove them from water sources are beginning to be used around the world.[97] The EPA already regulates some organophosphate pesticides due to their known adverse health effects, yet new regulations at the federal level have been repeatedly delayed. In late 2023, the EPA's 2021 ban on one specific neurotoxic organophosphate was lifted by an appeals court after a lawsuit by farmers and a pesticide manufacturer. At the state level, California, Hawaii, Maryland, New York, and Oregon have already banned the chemicals, and other states are considering similar legislation.[5] Regulation of nitrates has been successful in Europe—nitrate levels across Europe have averaged less than half the level deemed dangerous in the US since regulations were enforced in 1991.[5] *Nitrates and organophosphates should not be allowed in parks, schools, or other places dedicated to supporting young children, and regulations at the city, state, and federal levels must protect them.*

Policy Solutions Must Begin by Addressing Disparities

Communities across the US and around the world are experiencing an unprecedented array of threats to the supply of clean water for drinking, bathing, agriculture, cooking, and feeding babies. Threats such as flooding and drought are increasing due to climate change, making efforts to mitigate these threats—as well as to address their root causes by limiting the burning of fossil fuels—urgent. Many of these threats are the result of governance decisions and, therefore, can be addressed by making different decisions. Families, businesses, communities, states, and federal regulators are already taking practical steps to address the threats, but much more needs to be done.

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In 2010, the United Nations General Assembly explicitly recognized the human right to affordable and safe drinking water. The US abstained from voting on this resolution and has never recognized the human right to water, although 3 states reference it in law or state constitutions.[101] Instead, water has been treated in the context of property rights. Thus, high-profile negotiations among states, such as those involving the Colorado River in 2023, use a hierarchy of rights based on which entity made the first legal claim to the water, which typically excludes Indigenous people. As a result, Native American households are 19 times more likely to be without functional water and wastewater access than households identifying as White.[15] Another legalistic means of excluding specific communities from access to water is a practice known as racial "underbounding." Between the Civil War and the Civil Rights movement, many US cities and towns drew irregular boundaries that purposefully excluded communities of color from municipal incorporation. These communities were subsequently excluded from 20th-century investments in water and sanitation infrastructure. Many still rely on poor-quality services that differ starkly from their higher-income White neighbors.[102]

In addition, people who live in communities with higher proportions of non-Hispanic Black and Hispanic/Latino residents are more likely to be exposed to harmful levels of "forever chemicals" in their water supplies than people living in other communities due to the deliberate siting of manufacturing plants, airports, military bases, wastewater treatment facilities, and landfills near watersheds serving these communities.[103] Similar policy and zoning decisions have also placed marginalized and low-income populations in areas that are disproportionately affected by hurricanes and flooding, where a lack of civic investment in disaster preparedness compounds the geographic vulnerability. Finally, groups with strong personal and cultural ties to an area, such as Indigenous populations, may experience heightened levels of trauma if a destructive flood or drought forces them to move away.[36]

In order to support the healthy development of all children, no matter where they live, policy solutions must begin with redressing the legacy of these historical policies. Targeted public investment in water infrastructure—along with support for operating and maintaining this infrastructure—must be a key component for both large- and small-scale systems,[15] including private wells and mobile, adaptive, and decentralized systems that may be more cost-effective in rural areas.[104] Legislation should include explicit mechanisms to ensure that disproportionately affected, chronically neglected, and underserved communities are prioritized in the distribution and transparent management of funds.[15] As one example, in 2023, the EPA released information on $238 million in drinking water and wastewater infrastructure funding specifically set aside for Tribal groups.[105]

In addition to emphasizing fairness across the places where people live, a wide range of practical strategies for improving the quality and availability of the water supply and protecting children from harm are already being implemented at multiple levels, from private residences to communities, states, and federal oversight. Many community leaders and policymakers are already mobilizing to good effect, and empowering them to continue to lead such efforts is an important strategy. Below is a selection of immediate actions through which community leaders and policymakers can have an important impact. Parents, schools, health care practitioners, and community organizations can join together to demand these kinds of actions on behalf of children.

Improve and speed up protections and enforcement at the state and federal levels. Equal, vigorous enforcement of national standards for water protection is necessary to decrease everyone's exposure to contaminants. Environmental regulations should be based on input from community members, researchers, and healthcare providers, with attention to the impact of changes in regulation on child health and development. Federal agencies such as the EPA and a range of state agencies are the primary mechanisms for evaluating, implementing, and enforcing regulations that optimize the protection of child health. The EPA's Office of Child Health Protections, the National Institutes of Child Health and Development (NICHD), and the National Institute of Environmental Health Sciences (NIEHS) should continue to be well-supported to conduct research, which informs further policy development.[5] Ongoing attempts to defund or derail critical public health regulations and enforcement may protect the powerful economic interests of manufacturers, but they seriously endanger American lives and the healthy development of our children.

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Make water affordable. Customers pay the owners of water systems—some private, some municipal—for treating, storing, and delivering their water. In general, privately owned systems charge higher rates than municipal systems.[106] In a 2020 survey of the 12 largest municipal water utilities, more than 1.5 million households were in water debt, owing the utilities $1.1 billion in total.[107] In 2021, Congress created the Low Income Household Water Assistance Program (LIHWAP) to ensure that Americans unable to afford their water and wastewater bills could still receive these services, which were deemed vital to public health during the COVID-19 pandemic. Through September 2023, LIHWAP helped 1.4 million households in all 54 states and territories, as well as 93 tribes, maintain access to clean water.[108] For example, the mayors of Buffalo, New York, and Little Rock, Arkansas, reported to the National League of Cities that thousands of their constituents had maintained or restored access to water due to LIHWAP grants to their states. Unfortunately, LIHWAP was a time-limited pilot program that ended nationwide in March 2024. As the Buffalo and Little Rock mayors wrote, "A permanent LIHWAP program would not only help our constituents most in need but also ensure our entire communities can thrive."[109]

Support healthy development generally. While protecting all people from exposure to toxic contaminants should always be the primary goal, interventions that support child development and health across the lifespan have been shown to have positive impacts after an exposure. For example, some research suggests that providing enriched educational opportunities and supportive relationships may help reduce harm to children exposed to a neurotoxicant. Improvements to neighborhood and family economic opportunity may also lead to improved outcomes—children with socioeconomic advantages appear to demonstrate reduced effects from lead exposure, perhaps through the availability of support services and enrichment materials.[110] Other studies suggest that an enriched home environment moderates the adverse impacts of lead on both cognition and behavior[7] and that negative outcomes associated with early life exposure to lead can largely be reversed by interventions that remove lead and provide health and public assistance benefits for children whose blood lead levels exceed guidelines.[111] Finally, good nutrition from preconception to pregnancy to childhood has been found to support healthy development broadly and, in some cases, to be associated with reductions in blood levels of some water contaminants. For example, growing evidence suggest that increased consumption of folate can decrease blood arsenic levels[112,113] and higher levels of folate are also associated with lower concentrations of PFAS chemicals in the blood, indicating that folate may play a role in reducing the effect of exposure to "forever chemicals."[114]

Make testing and filtering widely available. There are many precedents for getting resources to people who need them, from farm subsidies to food stamps. Similar processes must overcome barriers to testing and filtering water from public and private sources. Practitioners in obstetrics and pediatrics might help prevent future health problems by connecting at-risk patients to relevant programs and subsidies. In Flint, for example, the Flint Registry, with funding from the CDC, has made more than 20,000 connections between families affected by the lead crisis and programs such as lead removal programs, health programs for expectant parents, and child health services.[69] After a flood, part of the disaster response should be widespread water quality testing, including of private wells, and testing for mold, allergies, and asthma in young children. The EPA offers a list of certified labs in every state that serve community water systems, small private systems, and private wells.[115] The EPA also offers a range of financial resources to support public water systems in enhancing drinking water quality and improving public health.[116] In addition, technologies such as point-of-use filtration systems can be deployed in a wide range of locations outside of public systems. For example, carbon filtration in a pitcher, reverse osmosis membrane filters, and ultraviolet light disinfection—or combinations of them—can all be deployed, depending on the quantities needed and the resources available. That said, the responsibility for purchasing and maintaining these filtration options should not replace the responsibility of public systems to supply clean drinking water, and subsidies or grants for those who cannot afford them will be needed to prevent further inequities.[117] Finally, the integration of Indigenous knowledge with biomedical science may reveal novel approaches to water filtration that fit within cultural traditions. For example, researchers working collaboratively with a Navajo community found that pottery widely used for water in that community could remove a wide range of bacteria by incorporating nanosilver into the ceramics.[118]

Improve the resilience of current water systems with hybrid models of "green" and "gray" infrastructure. Green infrastructure includes a variety of greenspaces that reduce runoff, filter out stormwater pollutants, and preserve water for times of drought. Gray infrastructure focuses on repairing or installing new sewer systems, holding tanks, water lines, flood barriers, and other structures to maximize the efficiency of systems and decrease the chance that waterways will be polluted or flooded. Combining improvements in these systems can better protect children by enhancing our systems' resilience to withstand storms and flooding.[119,120]

- **Green infrastructure improvements:** Planting trees, building bioswales (channels that carry stormwater), installing green roofs, and establishing new green spaces decrease water pollution by reducing runoff, decreasing flood risk, reducing the risk of sewer overflow, and replenishing groundwater stores.
- **Gray infrastructure:** Updating sewer systems and water storage facilities by repairing existing systems and installing new ones increases their capacity to handle higher water loads during floods and storms, which will reduce damage to homes and exposure to toxic health hazards for children and families.
- **Smart surfaces:** New pavement technologies, including porous asphalt and concrete, permeable pavers, and porous grid pavers with turf or gravel, allow rain to reenter the ground, reducing pollution, stormwater runoff, and flood risk while recharging groundwater that re-enters the aquifer.

Engage in "citizen science." In the face of delays and sometimes a complete absence of government response to water issues identified by the community, citizen-led action and solid data may be required to make the case and spur action. Community-engaged research can be a powerful tool for water quality research by involving the residents who are most affected by water issues. Academic-community partnerships across the country have been successful in mapping water contaminants and instigating protective measures in their communities. Such initiatives empower citizens with knowledge and agency to take concrete actions to improve their environment and can connect them to services such as legal support and university-based researchers.[66]

The use of community-engaged research in Flint demonstrated the power of quantifiable data to validate the anecdotal claims of residents affected by poor water quality. Citizen complaints alone did not convince city officials or national media of widespread illness caused by the water—and city and state officials either ignored complaints or refuted them with skewed data.[101] Ultimately, concerned residents and local activist groups had to form alliances with national activists, government employees, academics, and scientists to collect evidence that government institutions would deem credible. Together, leaders from the Flint community and a team of researchers and students trained citizen volunteers to collect water samples across the city. The test results substantiated local concerns: Lead levels were roughly 2 times higher than city tests had indicated. Virginia Tech professor Marc Edwards, who led the team of researchers, and pediatrician Mona Hanna-Attisha, director of the Michigan State University-Hurley Children's Hospital Pediatric Public Health Initiative, were able to amplify residents' claims by effectively communicating them in the language of scientific expertise. Combined, their efforts led to a local foundation offering to subsidize the cost of switching water supplies and to the mayor declaring a state of emergency in Flint—the beginning of a long process of addressing residents' concerns.[121] Even before the crisis gained national media attention, it was the sustained organization and activism of residents, coupled with scientific evidence, that sparked the return to a clean water system.[101]

Resources for Taking Action

Flint Registry: Resources for Other Communities
A nonprofit research and information organization established in Flint, Michigan, that offers helpful information, links, and tips relating to lead and other drinking water contaminants.
flintregistry.org/resources-for-other-communities

Water Data Collaborative
An online hub for participatory community water monitoring and using data to advocate for safer water.
waterdatacollaborative.org

River Network: State Action on Drinking Water
This guide provides examples of drinking water policies, plans, and resolutions in states across the US, addressing issues including affordability, lead, and PFAS.
rivernetwork.org/state-policy-hub/drinking-water

American Academy of Pediatrics (AAP) and AAP's HealthyChildren.org

- Is Your Drinking Water Safe? provides information and tips for caregivers on how to ensure the safety of their drinking water.
- Lead in Tap Water & Household Plumbing: Parent FAQs offers information and resources for protecting children from exposure to lead at home.
- Well Water Safety & Testing: AAP Policy Explained offers information and tips for families.

Children's Environmental Health Network: Eco-Healthy Child Care® Fact Sheets
The CEHN provides fact sheets for childcare providers on several topics in early health and development, including exposure to lead.

cehn.org/our-work/eco-healthy-child-care/ehcc-factsheets

Environmental Protection Agency
Offers a wide range of information, tools, funding opportunities, and case studies for individuals, organizations, and municipal water services. Below is a selection based on topics referenced in this report.

- Community-Based Water Resiliency Initiative provides communities with tools and resources to plan for and respond to water service disruptions, helping mitigate potentially severe health and economic consequences.
- Consumer Tool for Identifying POU Drinking Water Filters Certified to Reduce Lead helps consumers know if their water filter is certified to reduce lead.
- Contact Information for Certification Programs and Certified Laboratories for Drinking Water provides a searchable list of laboratories by state that will test private drinking water.
- Get the Lead Out Initiative is working to accelerate the removal of lead pipes, especially in underserved communities. Communities can request to participate in the initiative on this website.

- Green and Gray Infrastructure Research provides information and resources on green and gray infrastructure.
- Safe Drinking Water on Tribal Lands provides information and resources on how the EPA collaborates with Tribal governments, utilities, and members to implement the Safe Drinking Water Act.

Smart Surfaces Coalition

- What is a Smart Surface?
  This resource details what a smart surface is and how these surfaces can benefit communities, including how porous and permeable pavements can reduce stormwater runoff and water pollution.
- The Climate Is Changing Rapidly, But Smart Surface Technologies Can Help Keep Our Cities Cool examines how the climate is changing and the ways that smart surfaces can mitigate the impact of related weather events, including more frequent, heavy rains.

US Climate Resilience Toolkit: Water
Compiles information and examples of how climate change is affecting the water cycle, as well as case studies and suggestions of adaptations relating to municipal water supplies, flooding, drought, and more.
toolkit.climate.gov/topics/water

Centers for Disease Control and Prevention (CDC) Guide to Drinking Water
Includes information about water quality, testing, and treatment in public and private systems, homes, and while traveling.
cdc.gov/healthywater/drinking

References

1. Popkin BM, D'Anci KE, Rosenberg IH. Water, hydration, and health. Nutr Rev. Aug 2010;68(8):439-58. doi:10.1111/j.1753-4887.2010.00304.x
2. Medicine Io. Chapter 4: Water. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. National Academies Press; 2005:chap 73-185.
3. Li Y, Yuan Z, Yang H, Zhong H, Peng W, Xie R. Recent Advances in Understanding the Role of Cartilage Lubrication in Osteoarthritis. Molecules. Oct 11 2021;26(20) doi:10.3390/molecules26206122
4. Kimelberg HK. Water homeostasis in the brain: basic concepts. Neuroscience. 2004;129(4):851-60. doi:10.1016/j.neuroscience.2004.07.033
5. Bantol KEA, Brumberg HL, Shah SI, Javier JR. Perspectives from the Society for Pediatric Research: contaminants of water and children's health: Can we do better? Pediatr Res. Oct 2020;88(4):535-543. doi:10.1038/s41390-020-0985-4
6. National Scientific Council on the Developing Child. Place Matters: The Environment We Create Shapes the Foundations of Healthy Development: Working Paper No. 16. 2023. developingchild.harvard.edu
7. Bellinger DC, Matthews-Bellinger JA, Kordas K. A developmental perspective on early-life exposure to neurotoxicants. Environ Int. Sep 2016;94:103-112. doi:10.1016/j.envint.2016.05.014
8. Richey AS, Thomas BF, Lo MH, et al. Quantifying renewable groundwater stress with GRACE. Water Resour Res. Jul 2015;51(7):5217-5238. doi:10.1002/2015WR017349
9. Mendez E. A Climate Expert Explains Why Atmospheric Rivers Are Causing Historic Rainfall in California. Columbia University. Accessed Feb 5, 2024, news.climate.columbia.edu/2024/02/05/a-climate-expert-explains-why-atmospheric-rivers-are-causing-historicrainfall-in-california
10. US EPA. Basic Information about Nonpoint Source (NPS) Pollution. US Environmental Protection Agency. Accessed Mar 8, 2024, epa.gov/nps/basic-information-about-nonpoint-source-nps-pollution
11. Cushing L, Babson Dobbin K, Osborne Jelks N, Liu X, Morello-Frosch R. Health Affairs Health Policy Brief: Water Insecurity And Population Health: Implications For Health Equity And Policy. Oct 12, 2023 doi:10.1377/hpb20230921.68748
12. Georgakakos A, Fleming P, Dettinger M, et al. Ch 3: Water Resources. Climate Change Impacts in the United States: The Third National Climate Assessment. 2014:69-112. doi:10.7930/ J0G44N6T
13. Miller JD, Workman CL, Panchang SV, et al. Water Security and Nutrition: Current Knowledge and Research Opportunities. Adv Nutr. 2021;12(6):2525-2539. doi:10.1093/advances/nmab075
14. Meehan K, Jepson W, Harris LM, et al. Exposing the myths of household water insecurity in the global north: A critical review. WIREs Water. 2020;7(6):e1486. doi:10.1002/wat2.1486
15. Brown J, Acey CS, Anthonj C, et al. The effects of racism, social exclusion, and discrimination on achieving universal safe water and sanitation in high-income countries. The Lancet Global Health. 2023;11(4):e606-e614. doi:10.1016/S2214-109X(23)00006-2
16. Ahdoot S, Baum CR, Cataletto MB, et al. Climate Change and Children's Health: Building a Healthy Future for Every Child. Pediatrics. Mar 01 2024;153(3) doi:10.1542/peds.2023-065504
17. US EPA. US Climate Resilience Toolkit. US Environmental Protection Agency. Feb 22, 2024, toolkit.climate.gov
18. McAdam J, Bell EM. Determinants of maternal and neonatal PFAS concentrations: a review. Environ Health. 2023;22(1):41. doi:10.1186/s12940-023-00992-x
19. Hoadley L, Watters M, Rogers R, et al. Public health evaluation of PFAS exposures and breastfeeding: a systematic literature review. Toxicol Sci. 2023;194(2):121-137. doi:10.1093/toxsci/kfad053
20. Chouraqui JP. Children's water intake and hydration: a public health issue. Nutr Rev. Apr 11 2023;81(5):610-624. doi:10.1093/nutrit/nuac073
21. Mulyani EY, Hardinsyah, Briawan D, Santoso BI, Jus'at I. Effect of dehydration during pregnancy on birth weight and length in West Jakarta. J Nutr Sci. 2021;10:e70. doi:10.1017/jns.2021.59
22. Stephenson J, Heslehurst N, Hall J, et al. Before the beginning: nutrition and lifestyle in the preconception period and its importance for future health. Lancet. May 05 2018;391(10132):1830-1841. doi:10.1016/S0140-6736(18)30311-8
23. Taneja S, Chowdhury R, Dhabhai N, et al. Impact of a package of health, nutrition, psychosocial support, and WaSH interventions delivered during preconception, pregnancy, and early childhood periods on birth outcomes and on linear growth at 24 months of age: factorial, individually randomised controlled trial. BMJ. Oct 26 2022;379:e072046. doi:10.1136/bmj-2022-072046
24. Zhang Y, Mustieles V, Williams PL, et al. Association of preconception mixtures of phenol and phthalate metabolites with birthweight among subfertile couples. Environ Epidemiol. Oct 2022;6(5):e222. doi:10.1097/EE9.0000000000000222
25. Nobles CJ, Mendola P, Kim K, et al. Preconception Phthalate Exposure and Women's Reproductive Health: Pregnancy, Pregnancy Loss, and Underlying Mechanisms. Environ Health Perspect. Dec 2023;131(12):127013. doi:10.1289/EHP12287
26. Welch BM, McNell EE, Edin ML, Ferguson KK. Inflammation and oxidative stress as mediators of the impacts of environmental exposures on human pregnancy: Evidence from oxylipins. Pharmacol Ther. Nov 2022;239:108181. doi:10.1016/j.pharmthera.2022.108181
27. Barron A, McCarthy CM, O'Keeffe GW. Preeclampsia and Neurodevelopmental Outcomes: Potential Pathogenic Roles for Inflammation and Oxidative Stress? Mol Neurobiol. Jun 2021;58(6):2734-2756. doi:10.1007/s12035-021-02290-4
28. Lismer A, Shao X, Dumargne MC, et al. The Association between Long-Term DDT or DDE Exposures and an Altered Sperm Epigenome-a Cross-Sectional Study of Greenlandic Inuit and South African VhaVenda Men. Environ Health Perspect. Jan 2024;132(1):17008. doi:10.1289/EHP12013

29. Pross N. Effects of Dehydration on Brain Functioning: A Life-Span Perspective. Ann Nutr Metab. 2017;70 Suppl 1:30-36. doi:10.1159/000463060

30. Starnes HM, Rock KD, Jackson TW, Belcher SM. A Critical Review and Meta-Analysis of Impacts of Per- and Polyfluorinated Substances on the Brain and Behavior. Front Toxicol. 2022;4:881584. doi:10.3389/ftox.2022.881584

31. CDC. Nitrate/Nitrite Toxicity: Who Is at Most Risk of Adverse Health Effects from Overexposure to Nitrates and Nitrites? Agency for Toxic Substances and Disease Registry. Apr 2, 2024, Updated 2015. atsdr.cdc.gov/csem/nitrate-nitrite/who_risk.html

32. Finkelstein Y, Markowitz ME, Rosen JF. Low-level lead-induced neurotoxicity in children: an update on central nervous system effects. Brain Research Reviews. 1998/07/01 1998;27(2):168-176. doi:10.1016/S0165-0173(98)00011-3

33. Bondy SC, Campbell A. Water Quality and Brain Function. Int J Environ Res Public Health. Dec 21 2017;15(1) doi:10.3390/ijerph15010002

34. Raker EJ, Lowe SR, Arcaya MC, Johnson ST, Rhodes J, Waters MC. Twelve years later: The long-term mental health consequences of Hurricane Katrina. Soc Sci Med. Dec 2019;242:112610. doi:10.1016/j.socscimed.2019.112610

35. Richler J. Flood-induced displacement. Nature Climate Change. 2017/08/01 2017;7(8):547-547. doi:10.1038/nclimate3364

36. US EPA. Climate Change and Children's Health and Well-Being in the United States. EPA 430-R-23-001. 2023.

37. Suter MA, Aagaard KM. Natural disasters resulting from climate change: The impact of hurricanes and flooding on perinatal outcomes. Semin Perinatol. Dec 2023;47(8):151840. doi:10.1016/j.semperi.2023.151840

38. Conley MI, Skalaban LJ, Rapuano KM, et al. Altered hippocampal microstructure and function in children who experienced Hurricane Irma. Dev Psychobiol. Jul 2021;63(5):864-877. doi:10.1002/dev.22071

39. CDC. Syndromic Surveillance Shows Medical Surge in Dallas–Fort Worth during Hurricane Harvey, 2017. Centers for Disease Control and Prevention. Accessed Jan 14, 2024, archive.cdc.gov/www_cdc_gov/nssp/success-stories/TX-Hurricane-Harvey.html

40. Raker EJ, Arcaya MC, Lowe SR, Zacher M, Rhodes J, Waters MC. Mitigating Health Disparities After Natural Disasters: Lessons From The RISK Project. Health Aff (Millwood). Dec 2020;39(12):2128-2135. doi:10.1377/hlthaff.2020.01161

41. von Holst H, Nayak P, Dembek Z, et al. Perfluoroalkyl substances exposure and immunity, allergic response, infection, and asthma in children: review of epidemiologic studies. Heliyon. Oct 2021;7(10):e08160. doi:10.1016/j.heliyon.2021.e08160

42. National Scientific Council on the Developing Child. Connecting the Brain to the Rest of the Body: Early Childhood Development and Lifelong Health Are Deeply Intertwined: Working Paper No. 15. 2020. developingchild.harvard.edu

43. APHA. Drinking Water and Public Health in the United States. American Public Health Association. Updated Nov 5, 2019. apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2020/01/13/drinking-water-and-public-health-in-the-united-states

44. Levin R, Schwartz J. A better cost:benefit analysis yields better and fairer results: EPA's lead and copper rule revision. Environ Res. 2023/07/15; 229:115738. doi:10.1016/j.envres.2023.115738

45. NIH. Genetic Imprinting. National Human Genome Research Institute. Accessed Jan 14, 2024, genome.gov/genetics-glossary/Genetic-Imprinting

46. Nabi M, Tabassum N. Role of Environmental Toxicants on Neurodegenerative Disorders. Front Toxicol. 2022;4:837579. doi:10.3389/ftox.2022.837579

47. Abuawad A, Bozack AK, Saxena R, Gamble MV. Nutrition, one-carbon metabolism and arsenic methylation. Toxicology. 2021/06/15; 457:152803. doi:10.1016/j.tox.2021.152803

48. Ryan J, Chaudieu I, Ancelin ML, Saffery R. Biological underpinnings of trauma and post-traumatic stress disorder: focusing on genetics and epigenetics. Epigenomics. Nov 2016;8(11):1553-1569. doi:10.2217/epi-2016-0083

49. Cooley H, Ajami N, Ha M-L, et al. Global Water Governance in the Twenty-First Century. In: Gleick PH, ed. The World's Water: The Biennial Report on Freshwater Resources. Island Press/Center for Resource Economics; 2014:1-18.

50. CDC. Agricultural Water. Centers for Disease Control and Prevention. Accessed Jan 14, 2024, cdc.gov/agricultural-water/about

51. Soares JC, Santos CS, Carvalho SMP, Pintado MM, Vasconcelos MW. Preserving the nutritional quality of crop plants under a changing climate: importance and strategies. Plant and Soil. 2019/10/01 2019;443(1):1-26. doi:10.1007/s11104-019-04229-0

52. Wan C, Dang P, Gao L, et al. How Does the Environment Affect Wheat Yield and Protein Content Response to Drought? A Meta-Analysis. Front Plant Sci. 2022;13:896985. doi:10.3389/fpls.2022.896985

53. Trentacosta CJ, Mulligan DJ. New directions in understanding the role of environmental contaminants in child development: Four themes. New Directions for Child and Adolescent Development. 2020(172):39-51. doi:10.1002/cad.20363

54. Słota M, Wąsik M, Stołtny T, Machoń-Grecka A, Kasperczyk S. Effects of environmental and occupational lead toxicity and its association with iron metabolism. Toxicology and Applied Pharmacology. 2022/01/01 2022;434:115794. doi:10.1016/j.taap.2021.115794

55. Bae S, Kamynina E, Guetterman HM, et al. Provision of folic acid for reducing arsenic toxicity in arsenic-exposed children and adults. Cochrane Database of Systematic Reviews. 2021;(10). doi:10.1002/14651858.CD012649.pub2

56. CDC. Drinking Water: Public Water Systems. Centers for Disease Control and Prevention. Accessed Jan 14, 2024, cdc.gov/healthywater/drinking/public

57. Mizelle R. A Slow-Moving Disaster — The Jackson Water Crisis and the Health Effects of Racism. N Engl J Med. 2023;388(24):2212-2214. doi:10.1056/NEJMp2212978

58. Salhotra P, Carver J. A boil-water notice in Houston made national news. In rural Texas, it's a way of life. The Texas Tribune. Dec 7, 2022.

59. Mueller J, Gasteyer S. The widespread and unjust drinking water and clean water crisis in the United States. Nature Communications. 2021;12(1):3544. doi:10.1038/s41467-021-23898-z

60. Switzer D, Teodoro MP. Class, Race, Ethnicity, and Justice in Safe Drinking Water Compliance*. Social Science Quarterly. 2018;99(2):524-535. doi:10.1111/ssqu.12397

61. Deitz S, Meehan K. Plumbing Poverty: Mapping Hot Spots of Racial and Geographic Inequality in U.S. Household Water Insecurity. Annals of the American Association of Geographers. 2019/07/04 2019;109(4):1092-1109. doi:10.1080/24694452.2018.1530587

62. Levin R, Villanueva CM, Beene D, et al. US drinking water quality: exposure risk profiles for seven legacy and emerging contaminants. Journal of Exposure Science & Environmental Epidemiology. 2024/01/01 2024;34(1):3-22. doi:10.1038/s41370-023-00597-z

63. Marvel K, Su W, Delgado R, et al. Climate trends. In: Crimmins AR, Avery CW, Easterling DR, Kunkel KE, Stewart BC, Maycock TK, eds. Fifth National Climate Assessment. US Global Change Research Program; 2023:chap 2.

64. ASCE. 2021 Report Card for America's Infrastructure. infrastructurereportcard.org

65. Porter K. A Case Study of Flood Protection for a Water Treatment Plant. 2020. sparisk.com/pubs/Porter-2020-Greenville.pdf

66. Evans S, Zajac L. We can and we must do better to protect children from drinking water contaminants. Pediatric Research. 2020/10/01 2020;88(4):529-532. doi:10.1038/s41390-020-1062-8

67. Fedinick K, Taylor S, Roberts M. Watered Down Justice. 2019. nrdc.org/sites/default/files/watered-down-justice-report.pdf

68. CDC. Drinking Water: Water Treatment. Centers for Disease Control and Prevention. Accessed Jan 14, 2024, cdc.gov/healthywater/drinking/public/water_treatment.html

69. Hanna-Attisha M, LaChance J, Starrs L. Flint Lead Free 2023 Report: Data Trends & Multi-Sector Collaboration. 2023.

70. Rhyan C, Miller G, Betanzo E, Hanna-Attisha M. Removing Michigan's Lead Water Service Lines: Economic Savings, Health Benefits, And Improved Health Equity. Health Aff (Millwood). Aug 2023;42(8):1162-1172. doi:10.1377/hlthaff.2022.01594

71. US EPA. Biden-Harris Administration Proposes to Strengthen the Lead and Copper Rule to Protect All Communities in America from Lead in Drinking Water. US Environmental Protection Agency. Updated Nov 30, 2023. epa.gov/newsreleases/biden-harris-administration-proposes-strengthen-lead-and-copper-rule-protect-all

72. Pell M, Schneyer J. A Quest for Clean Water: The corrosive dangers lurking in private wells. Reuters.

73. Nigra AE. Environmental racism and the need for private well protections. Proceedings of the National Academy of Sciences. 2020;117(30):17476-17478. doi:10.1073/pnas.2011547117

74. Wasserman GA, Liu X, LoIacono NJ, et al. A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren. Environmental Health. 2014/04/01 2014;13(1):23. doi:10.1186/1476-069X-13-23

75. Bair E. A Narrative Review of Toxic Heavy Metal Content of Infant and Toddler Foods and Evaluation of United States Policy. Review. Frontiers in Nutrition. 2022/06/27 2022;9. doi:10.3389/fnut.2022.919913

76. Vaidya N, Holla B, Heron J, et al. Neurocognitive Analysis of Low-level Arsenic Exposure and Executive Function Mediated by Brain Anomalies Among Children, Adolescents, and Young Adults in India. JAMA Network Open. 2023;6(5):e2312810-e2312810. doi:10.1001/jamanetworkopen.2023.12810

77. USGS. Arsenic and Drinking Water. US Geological Survey: Water Resources Mission Area. Accessed Jan 14, 2024, usgs.gov/mission-areas/water-resources/science/arsenic-and-drinking-water

78. NIH. Arsenic. National Institute of Environmental Health Sciences. Accessed Jan 25, 2024, niehs.nih.gov/health/topics/agents/arsenic

79. US EPA. Proposed Lead and Copper Rule Improvements. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/ground-water-and-drinking-water/proposed-lead-and-copper-rule-improvements

80. US EPA. Identifying Funding Sources for Lead Service Line Replacement. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/ground-water-and-drinking-water/identifying-funding-sources-lead-service-line-replacement

81. CDC. Childhood Lead Poisoning Prevention: CDC Updates Blood Lead Reference Value. Centers for Disease Control and Prevention. Accessed Jan 14, 2024, cdc.gov/lead-prevention/php/news-features/updates-blood-lead-reference-value.html

82. AAP. Detection of Lead Poisoning. American Academy of Pediatrics. Accessed May 31, 2024, aap.org/en/patient-care/lead-exposure/detection-of-lead-poisoning

83. Schneyer J, Pell M. Unsafe at Any Level: Millions of American children missing early lead tests, Reuters finds. Reuters.

84. State Lead Screening Policies and Reporting Requirements. Accessed Jan 14, 2024. toxicfreefuture.org/research/children-at-risk/state-lead-screening-policies

85. US EPA. Drinking Water Arsenic Rule History. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/dwreginfo/drinking-water-arsenic-rule-history

86. Spaur M, Lombard MA, Ayotte JD, et al. Associations between private well water and community water supply arsenic concentrations in the conterminous United States. Science of The Total Environment. 2021/09/15 2021;787:147555. doi:10.1016/j.scitotenv.2021.147555

87. US EPA. Arsenic Rule Compliance for Community Water System Owners and Operators. US Environmental Protection Agency. Accessed January 14, 2024, epa.gov/dwreginfo/arsenic-rule-compliance-community-water-system-owners-and-operators

88. Blake BE, Fenton SE. Early life exposure to per- and polyfluoroalkyl substances (PFAS) and latent health outcomes: A review including the placenta as a target tissue and possible driver of peri- and postnatal effects. Toxicology. 2020/10/01/ 2020;443:152565. doi:10.1016/j.tox.2020.152565

89. Pozzebon EA, Seifert L. Emerging environmental health risks associated with the land application of biosolids: a scoping review. Environmental Health. 2023/08/21 2023;22(1):57. doi:10.1186/s12940-023-01008-4

90. Wang Y, Qian H. Phthalates and Their Impacts on Human Health. Healthcare. 2021;9(5):603.

91. Ziani K, Ioniță-Mîndrican C-B, Mititelu M, et al. Microplastics: A Real Global Threat for Environment and Food Safety: A State of the Art Review. Nutrients. 2023;15(3):617.

92. Hlisníková H, Petrovičová I, Kolena B, Šidlovská M, Sirotkin A. Effects and Mechanisms of Phthalates' Action on Reproductive Processes and Reproductive Health: A Literature Review. International Journal of Environmental Research and Public Health. 2020;17(18):6811.

93. Rodgers KM, Swartz CH, Occhialini J, Bassignani P, McCurdy M, Schaider LA. How Well Do Product Labels Indicate the Presence of PFAS in Consumer Items Used by Children and Adolescents? Environmental Science & Technology. 2022/05/17 2022;56(10):6294-6304. doi:10.1021/acs.est.1c05175

94. Wutich A, Jepson W, Velasco C, et al. Water insecurity in the Global North: A review of experiences in U.S. colonias communities along the Mexico border. WIREs Water. 2022;9(4):e1595. doi:10.1002/wat2.1595

95. Woolf AD, Stierman BD, Barnett ED, et al. Drinking Water From Private Wells and Risks to Children. Pediatrics. Feb 1 2023;151(2). doi:10.1542/peds.2022-060645

96. US EPA. Overview of the Safe Drinking Water Act. US Environmental Protection Agency. Accessed May 2, 2024, epa.gov/sdwa/overview-safedrinking-water-act

97. Syafrudin M, Kristanti RA, Yuniarto A, et al. Pesticides in Drinking Water-A Review. Int J Environ Res Public Health. Jan 8 2021;18(2). doi:10.3390/ijerph18020468

98. Lushchak VI, Matviishyn TM, Husak VV, Storey JM, Storey KB. Pesticide toxicity: a mechanistic approach. EXCLI J. 2018;17:1101-1136. doi:10.17179/excli2018-1710

99. Reed NR, Lim LO. Organophosphate Insecticides: Neurodevelopmental Effects. In: Nriagu JO, ed. Encyclopedia of Environmental Health. Elsevier; 2011:283-290.

100. Dorsey ER, Zafar M, Lettenberger SE, et al. Trichloroethylene: An Invisible Cause of Parkinson's Disease? Journal of Parkinson's Disease. 2023;13:203-218. doi:10.3233/JPD-225047

101. Gaber N. Mobilizing Health Metrics for the Human Right to Water in Flint and Detroit, Michigan. Health Hum Rights. Jun 2019;21(1):179-189.

102. Aiken CS. Race as a Factor in Municipal Underbounding. Annals of the Association of American Geographers. 1987;77(4):564-579. doi:10.1111/j.1467-8306.1987.tb00181.x

103. Liddie JM, Schaider LA, Sunderland EM. Sociodemographic Factors Are Associated with the Abundance of PFAS Sources and Detection in U.S. Community Water Systems. Environ Sci Technol. May 30 2023;57(21):7902-7912. doi:10.1021/acs.est.2c07255

104. Stoler J, Jepson W, Wutich A, et al. Modular, adaptive, and decentralised water infrastructure: promises and perils for water justice. Current Opinion in Environmental Sustainability. 2022/08/01/ 2022;57:101202. doi:10.1016/j.cosust.2022.101202

105. US EPA. Safe Drinking Water on Tribal Lands. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/tribaldrinkingwater

106. El-Khattabi AR, Gmoser-Daskalakis K, Pierce G. Keep your head above water: Explaining disparities in local drinking water bills. PLOS Water. 2023;2(12):e0000190. doi:10.1371/journal.pwat.0000190

107. Patterson LA, Doyle MW. Measuring water affordability and the financial capability of utilities. AWWA Water Science. 2021;3(6):e1260. doi:10.1002/aws2.1260

108. US DHHS. Low Income Household Water Assistance Program (LIHWAP). US Department of Health & Human Services Office of Community Services. Accessed Jan 14, 2024, acf.hhs.gov/ocs/programs/lihwap

109. Brown B, Scott Jr. F. How the Low-Income Household Water Assistance Program Supports Residents in Buffalo and Little Rock. National League of Cities. Updated Dec 13, 2023. nlc.org/article/2023/12/13/how-the-low-income-household-water-assistance-program-supports-residents-in-buffalo-and-little-rock

110. Bellinger DC. Lead neurotoxicity and socioeconomic status: Conceptual and analytical issues. NeuroToxicology. 2008/09/01/ 2008;29(5):828-832. doi:10.1016/j.neuro.2008.04.005

111. Billings SB, Schnepel KT. Life after Lead: Effects of Early Interventions for Children Exposed to Lead. American Economic Journal: Applied Economics. 2018;10(3):315-44. doi:10.1257/app.20160056

112. Wendee N. FACT Finding: Folic Acid Supplementation May Lower Risk from Arsenic in Drinking Water. Environmental Health Perspectives. 2023;131(7):074001. Doi:10.1289/EHP13153

113. Kile ML, Ronnenberg AG. Can folate intake reduce arsenic toxicity? Nutrition Reviews. 2008;66(6):349-353. doi:10.1111/j.1753-4887.2008.00043.x

114. Zhang Y, Mustieles V, Wang Y-X, et al. Folate concentrations and serum perfluoroalkyl and polyfluoroalkyl substance concentrations in adolescents and adults in the USA (National Health and Nutrition Examination Study 2003&2013;16): an observational study. The Lancet Planetary Health. 2023;7(6):e449-e458. doi:10.1016/S2542-5196(23)00088-8

115. US EPA. Contact Information for Certification Programs and Certified Laboratories for Drinking Water. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/dwlabcert/contact-information-certification-programs-and-certified-laboratories-drinking-water

116. US EPA. Drinking Water Grants. US Environmental Protection Agency. Accessed Jan 14, 2024, epa.gov/ground-water-and-drinking-water/drinking-water-grants

117. Wutich A, Thomson P, Jepson W, et al. MAD water: Integrating modular, adaptive, and decentralized approaches for water security in the climate change era. WIREs Water. 2023;10(6):e1680. doi: 10.1002/wat2.1680

118. Rowles LS, Tso D, Dolocan A, Kirisits MJ, Lawler DF, Saleh NB. Integrating Navajo Pottery Techniques To Improve Silver Nanoparticle-Enabled Ceramic Water Filters for Disinfection. Environmental Science & Technology. 2023/11/07 2023;57(44):17132-17143. doi:10.1021/acs.est.3c03462

119. US EPA. Green and Gray Infrastructure Research. US Environmental Protection Agency. Accessed May 18, 2024, epa.gov/water-research/green-and-gray-infrastructure-research

120. Hendricks MD, Dowtin AL. Come hybrid or high water: Making the case for a Green–Gray approach toward resilient urban stormwater management. JAWRA Journal of the American Water Resources Association. 2023;59(5):885-893. doi:10.1111/1752-1688.13112

121. Krings A, Kornberg D, Lane E. Organizing Under Austerity: How Residents' Concerns Became the Flint Water Crisis. Critical Sociology. 2019;45(4-5):583-597. doi:10.1177/0896920518757053

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