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Priorities for a New Decade: Weather, Water, and Climate

American Meteorological Society

In order to prosper, the United States – its government, businesses, institutions, and people – relies on a wealth of physical resources. Food, water, and energy are essential, as is a life-supporting environment. Our future also rests on a bedrock expectation: that we are resilient enough to survive whatever the environment throws at us. Resilience includes having advance warning of weather hazards and safe shelter when needed. It also includes knowing what to expect and how we might respond as the byproducts of our technological success – carbon emissions – act to warm and transform our atmosphere, oceans, and biosphere.

All of us are vulnerable to the impacts of weather extremes and climate change. Each person's risk will be influenced by where they live, socioeconomic status, family and community ties, societal structures, the presence or absence of racial discrimination, and many other factors. No matter who we are, we rely on environmental knowledge. Those who generate and use that knowledge are accountable to the nation and its people.

The United States benefits greatly from the world's largest assembly of specialists in weather, water, and climate (WWC), working in federal, state, and local government (the public sector), private firms, nongovernmental organizations (NGOs), and academia. Together, as a multifaceted enterprise, they supply Americans with crucial guidance on the behavior of the environment that shapes the lives of us all.

The decade of the 2020s will see new demands placed on the WWC enterprise – challenges that highlight the need to protect and enhance the nation's capabilities, economic strengths, resilience, and equity. Ironically, some of these challenges arise from technological progress itself. Among these challenges:

- new types of data from new platforms
- the intersection of climate change and societal change
- new sources of WWC information
- potential interference with WWC observing capabilities and operations

These examples point to two pressing needs:

- to have the WWC information required to avoid harmful consequences and enable new opportunities
- to use that information as effectively as possible

Policy makers at local, state, and federal levels will be hugely important in determining the extent to which these two needs are met.

WWC information must be as accurate, complete, accessible, and actionable as possible. The COVID-19 pandemic has brought home the enormous value of having timely, relevant information at hand when a crisis is looming. The nation must invest in the human and institutional foundation that undergirds WWC information so that the full spectrum of our people and communities have access to the best possible guidance on what to expect from our environment, when to expect it, and how they can respond to it. Increased diversity, equity, inclusion, and accessibility are paramount to accelerating the advancement of science and bringing the WWC workforce into alignment with the nation's population and its evolving needs. Economic and social prosperity belong to a society that understands and effectively responds to Earth's changing WWC conditions.

Environmental forecasts provide a range of value at different time scales. At each of these time frames, experts and stakeholders from a diverse range of regional, social, institutional, and disciplinary backgrounds must join forces to better understand what people and communities need to know to make the best use of advances in weather and climate guidance. The results could yield benefits across the spectrum of user needs and time frames, from minutes to decades and beyond.

With this context in mind, the AMS prepared the seven recommendations below for policies resulting in a strong WWC enterprise equipped to support services and research critical to societal health and resilience. Challenges to the implementation of these policies remain, and their implications on forecasts and other services vary according to the lead time. These considerations are highlighted below.

Evolving challenges

- **New types of data from new platforms.** WWC data come from the public, private, and academic sectors, as well as from NGOs. Each component is critical to the WWC enterprise, as are the ways that the sectors collaborate and compete. This is particularly true given the rapidly increasing array of observational systems now being created and deployed. These data have the potential to strengthen the forecasts reaching Americans and to enhance our broader understanding of the atmosphere and oceans. By the year 2030, the national network of satellite-based sensors used in daily weather forecasting will be due for an upgrade, one that could potentially draw on the array of newly developed tools.

  However, there is no overarching policy to ensure that data from these new platforms are as consistent and reliable as possible, that forecasting systems can reap the maximum benefit from them, and that they will be available over the longer-term time frame needed to assess climate variability and change. Careful and continuous consideration of roles and responsibilities among the public, private, academic, and NGO communities will thus be critical as capabilities, interests, and needs evolve over the next decade and beyond.

- **The intersection of climate change and societal change.** Intensive observations and research over the past four decades have shown that people are causing climate to change and that human-caused climate change is dangerous and the consequences potentially dire. Global temperature hit record highs for three consecutive years in the 2010s. Further warming is expected in the 2020s and beyond, from greenhouse gases already added to the atmosphere and from additional emissions still to come. The latter will depend greatly on choices made by society over the next few years.

Renewable Natural Resources Foundation

The Renewable Natural Resources Foundation (RNRF) is a nonprofit, public policy research organization. Its mission is to advance the application of science, engineering and design in decision-making, promote interdisciplinary collaboration, and educate policymakers and the public on managing and conserving renewable natural resources. Member organizations are:

American Geophysical Union • American Meteorological Society
American Society of Civil Engineers • American Society of Landscape Architects Fund
American Water Resources Association • Geological Society of America
Society of Environmental Toxicology and Chemistry

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Climate change is not only altering Earth's physical and biological systems but also affecting every societal and economic sector, from infrastructure to agriculture to energy supply and demand. As one example, intensified drought impacts can lead to large-scale migration across international borders, which in turn can fuel regional conflict and instability. Those who are marginalized tend to be most vulnerable to the manifold changes and crises triggered directly or indirectly by a changing climate.

In many parts of the nation, emerging climate trends are compounding societal stresses. For example, persistent weather patterns atop rising mean sea level sent water above high tide in 2019 for more than 2000 hours in the Miami area, where real estate is already being affected by concerns about long-term sea level rise. In Texas, record downpours produced by Hurricane Harvey in 2017 were consistent with global trends toward intensified rainfall extremes, and the catastrophic floods that resulted were exacerbated by sprawl in the Houston area. In California – where development has increasingly pushed into fire-prone forests and where dry periods are increasingly accompanied by record heat – a string of wildfires in 2017-18 took an unprecedented toll in life and property. Millions of Californians were affected by utility power cuts intended to reduce risk during fire-prone weather. Predicting and responding to such multipronged threats will require new forms of collaboration and data sharing across sectors and disciplines.

Another task for the research community will be to ensure that efforts to address climate change work to reduce rather than to exacerbate social inequities. For example, if not thoughtfully designed, a cap-and-trade program that reduces total emissions across a state or region may allow the remaining pollution to become even more concentrated in marginalized communities. With increased awareness, physical and social scientists can work with affected populations to repair or avert disproportionate harms they may suffer, whether from climate change itself or from efforts to address it.

- **New sources of WWC information.** The proliferation of smartphones and social media gives Americans virtually nonstop access to information, and it lays the groundwork for weather warnings to be much more specific in time and location. However, new forms of media can also make it more difficult for consumers to assess the source and/or accuracy of weather information. This gap may lead to public vulnerability at times when deadly weather threatens or when major decisions loom.
- **Potential interference with WWC observing capabilities and operations.** Weather, water, and climate operations rely on the radio frequency spectrum to observe the Earth system (e.g., with satellites, weather radars, and wind profilers) and to transmit crucial information. The radio frequency spectrum is a limited resource, and competition for it is intense and growing, particularly with the opportunity to expand 5G access. This competition puts WWC-related uses of the radio spectrum at risk. It will be extremely important for decision-makers to understand and account for meteorological uses of the radio spectrum before reallocation decisions are made.

How policy affects WWC services on different time scales

Predictions across the traditional weather-forecast window of about one day to two weeks remain tremendously important to a variety of users. These forecasts can be improved and leveraged further in a variety of ways – for instance, incorporating multiday rainfall forecasts more completely into flood outlooks and water resource management.

Forecasts at other time scales offer their own benefits and challenges. Three illustrative examples are shown below. This is not a complete list; other examples could be created for each time scale, from minutes to decades and beyond.

- **One to three hours.** Our national investment in research and observations has paved the way for severe weather guidance to extend beyond traditional 30- to 60-minute warnings into the 1- to 3-hour time frame. Such guidance could lead to major benefits in preparation and safety. It also raises new questions. How will people respond if they expect to have more than an hour to take action ahead of a possible tornado or a flash flood? How can the probabilities and uncertainties inherent in such guidance best be conveyed? How can schools, workplaces, and other institutions act to support public safety measures in these extended time frames?

- **Weeks to months.** Specific local weather forecasts cannot be issued with accuracy beyond about 10 to 14 days. However, many other types of outlooks have demonstrated accuracy over periods of weeks to months (subseasonal to seasonal periods) when they are presented in terms of probabilities or likelihoods. For example, some periods of increased regional tornado risk may be predictable more than three weeks in advance. The progression of the Madden-Julian oscillation can signal enhanced probabilities of hurricane development weeks ahead of time. The development of El Niño and La Niña events can provide months of advance notice on which parts of the nation are most likely to experience winters that are wetter, drier, warmer, or colder than usual. Utilities, agriculture, and other economic sectors already save money based on such seasonal outlooks. How can the science underlying these outlooks be improved, and how can the resulting probabilities – which are often complex in nature – be presented in terms that are even more useful to the public and other stakeholders, allowing for even greater economic and safety benefits? For example, how can forecast confidence be incorporated and communicated so that users know whether a given situation is likely to produce a more-skillful or less-skillful forecast?
- **Five to ten years.** Billions of dollars of infrastructure must be deployed across the nation over the coming decade and beyond to ensure safe water supplies, protect communities from flooding, and meet many other goals. WWC guidance is critical to developing infrastructure that will fit the needs of today, tomorrow, the next decade, and decades to come, in a changing climate. What aspects of climate change are likely to emerge most quickly in the 2020s, and how will these intersect with societal change? How can research best support the tools that are needed to understand and respond to these changes?

Recommendations

Develop the Next Generation of WWC Experts

It is essential to foster a diverse and inclusive workforce where representatives of all members of our society feel welcome. To ensure this workforce is equipped to enable scientific and technological advances, apply science for the benefit of all people, and inform WWC decisions, investments must continue to: (i) educate and train students for careers in science, technology, engineering, and mathematics; and (ii) develop a new generation of WWC researchers. Environmental awareness and professional integrity are crucial values to instill in the next generation of WWC experts.

Invest in Research Critical to Innovation and Advanced Services

To ensure continued leadership in understanding our complex and changing planet and application of this understanding for the benefit of society, increased investments are needed to support new discoveries, innovation, applications, and model development in the geosciences, engineering, and relevant social sciences.

Invest in Observations and Computing Infrastructure

To ensure advances in scientific knowledge and more accurate and timely delivery of WWC products and support services at scales useful to decision-makers, and to preserve national security, targeted investments are required for:

- atmosphere-ocean-land-ice observational infrastructure
- techniques to translate the resulting large datasets into forms suitable for information services and prediction models
- leading-edge high-performance computers and software, including weather and climate models that incorporate the components of the Earth system in interactive fashion
- observation quality control, including enhanced diagnosis of observation error and improvements in automated observing systems

Create Services that Harness Scientific Advances for Societal Benefit

To ensure society's most pressing needs are met and its capabilities are optimally utilized, mechanisms for engaging a variety of users and moving research into practical applications in a timely and effective fashion must be encouraged, developed, and implemented. In particular, open access to data and publications is an increasingly powerful tool for distributing the fruits of scientific labor as widely as possible.

Prepare Informed WWC Information Users

To ensure we have informed users who can take full advantage of advanced WWC information and tools, education and communication programs must continue to focus on enhancing WWC skills and understanding by both decision-makers and society at large. These efforts should draw on insights from both physical and social science and should involve collaborations among scientists and decision-makers to maximize user feedback and the co-production of knowledge.

Build Strong Partnerships Throughout the WWC Enterprise

Private companies, government officials, academic researchers, and the NGO community have always worked together to meet America's WWC challenges. As this task grows more consequential, urgent, and complex, a coordinated federal effort is needed to support, strengthen, and encourage strategic inter-sector partnerships, including efforts to increase the global suite of Earth observations, advance long-term stewardship of environmental data, and improve national and international community-level resilience to climate change and variability. Such partnerships must also be extended to related disciplines, including energy, transportation, health, and decision support.

Implement Effective Leadership and Management

To ensure that WWC investments are made in the best interests of the nation, effective leadership and management approaches will be needed, including: (i) appointing highly capable, well-qualified, and diverse leadership to top WWC policy positions in the White House and federal agencies, and (ii) implementing management approaches that support integrated WWC research and services planning across federal agencies and Congress. These structures should proactively engage the academic and private sectors.

California to Monitor Microplastic Pollution in Drinking Water and Marine Environments –

Addressing the environmental and health impacts of microplastics requires open collaboration among diverse sectors

Scott Coffin, Holly Wyer, and J.C. Leapman

Introduction

Recent polls suggest the public is aware of and concerned about the effects of plastic pollution on the environment and public health.[1–3] Microplastics (typically defined as plastic particles smaller than 5 mm[4]) are found virtually everywhere, including in aquatic and terrestrial ecosystems,[5,6] air,[7] drinking water,[8] food,[9] and even remote alpine and polar settings.[10,11] Adverse impacts of plastic pollution, particularly microplastics, are becoming better understood in aquatic ecosystems,[12,13] with exceedances of risk thresholds documented in several ecosystems.[14] However, uncertainties regarding impacts remain, largely due to uncharacterized hazards and sampling bias towards larger-sized particles (which are believed to be less toxic).[12,15] Greater uncertainties remain in assessing impacts to humans, which have received far less research attention than ecological receptors.[16]

Generally, the public relies on the government to address environmental issues and often promotes policy and regulatory actions through citizen's groups and nongovernmental organizations.[17] Accordingly, regulators and policymakers around the world have taken various actions to mitigate environmental and public health impacts.[18] Microplastics present unique challenges to risk assessors and decision-makers due to their extreme diversity of composition,[19] insolubility, adsorbed and intentionally added contaminants,[20] and complex, heterogeneous occurrence in the environment.[21]

Despite these challenges, government agencies around the world are implementing various actions to mitigate known and unknown impacts of microplastics on public health and the environment. These actions range from upstream measures, such as Taiwan's ban on single-use plastics,[22] to downstream measures such as California's discharge requirements of macro-sized debris into waterways.[23] While local and national efforts to reduce impacts of microplastics are valuable, international strategies and reduction targets such as the 1978 Protocol to the International Convention for the Preservation of Pollution from Ships (MARPOL)[24] are needed to significantly mitigate impacts.[25] In addition to the need for international cooperation in addressing impacts of microplastics, close intersector collaboration between scientists, regulators, and policymakers is paramount to advance policy and mitigation options available to local and national governments to reduce microplastic emissions. Such collaborative efforts may be exemplified in the State of California, which recently has enacted 2 groundbreaking pieces of legislation to address impacts of microplastics in drinking water and the marine environment to respond to increasing public concern.[26,27]

This paper highlights several aspects of microplastics, which present unprecedented challenges for mitigating impacts, thus requiring close collaboration

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between stakeholders; uses California as a case study to offer insights on addressing some of these issues; and identifies actions that regulators, policymakers, and researchers can take to advance the field and develop effective pollution intervention strategies. Throughout this paper, we will refer to another regulatory paradigm disruptor—per- and polyfluoroalkyl substances (PFAS)—for insight and lessons learned when addressing microplastics.

The combination of global environmental contamination, persistence, and uncertainties regarding effects on vital earth system processes satisfy the conditions for both PFAS and microplastics to be classified as "planetary boundary threats"—defined as factors that may irreversibly threaten the earth systems that allow humanity to thrive.

Microplastics challenge traditional risk-based regulatory paradigms

Innovations in risk assessment frameworks and regulatory approaches may be required to protect environmental and public health from complex contaminant classes and mixtures with vast uncertainties in their environmental fate and transport, exposure, and hazards. The traditional framework for assessing risk is by comparing exposure amounts with known hazard thresholds.[28] Many regulatory frameworks are based on this traditional risk assessment framework and set regulatory thresholds (e.g., maximum contaminant levels in drinking water, effluent limits in wastewater discharge) based on estimated exposures which would theoretically exceed certain risk thresholds.[29,30] While this traditional risk assessment-based regulatory framework works well for single-chemical contaminants or relatively simple mixtures of contaminants with known chemical structures, compositions, and biological activities (e.g., dioxins and dioxin-like polychlorinated biphenyls (PCBs)[10]), it may be inadequate to address risks from more complex contaminants.

The term "microplastics" encompasses a vast universe of particles that present unique challenges in estimating risks due to their extreme diversity (e.g., size, shape, solubility, polymer composition, sorbed chemicals and biota, etc.).[19] Even defining the contaminant class has been a matter of lengthy debate.[4,31] In order to estimate risks and regulate microplastics using traditional frameworks, recent innovative efforts have tried to reduce complexities associated with the high number of variables used to classify microplastics (i.e., size, shape, polymer types).[32] However, such simplification efforts are unlikely to satisfactorily capture the full variability of shapes of microplastics, leading to underestimates of risk.[32]

A recent study on wild-caught, commercially important fish found that microplastics ingested by the fish likely transferred bisphenol A (BPA) and related analogues into their tissue at high enough quantities to exceed risk thresholds in adults and children at mean ingestion rates of the fish.[33] Notably, the study would not have estimated an exceedance of risk threshold if the authors had used the United States Environmental Protection Agency's (US EPA) risk value for BPA,[34] which is 12.5 times higher than the European Food Safety Authority's value.[35] This study highlights both the importance of characterizing plastic-associated chemicals in microplastics (a key hazard trait)[36–39] and assessing hazards of endocrine-disrupting chemicals (e.g., BPA, di-2-ethylhexyl-phthalate) commonly added to plastics.[37,40] Assessing hazards for some endocrine-disrupting chemicals may be complicated due their exhibiting nonmonotonic dose–response effects (i.e., effects observed at low concentrations are not predicted by and/or observed at higher concentrations).[41–43] When such nonmonotonic effects are considered, such compounds may be considered substantially more toxic.[44]

Another critical challenge in assessing risks of plastic-associated chemicals is that most plastic additives (approximately 80%) have their identities hidden from researchers, regulators, and the public, protected as "confidential business information" (CBI), or lack adequate documentation in public databases (see more on

Box 1. Unknown chemicals present never-ending challenges for risk assessors

There is an increasing worldwide trend of approving unknown chemicals and mixtures for use in commerce, thus providing scientists and regulators with a Sisyphean task in estimating risks for over 70,000 such chemicals/mixtures (>37,000 of which are polymers).[46] This increasing trend is in spite of regulations that apparently intend to prevent the introduction of "regrettable substitutions" into the environment, such as the 2016-revised Toxic Substances Control Act (TSCA) in the United States (US)[48] and the European Union's more aggressive Registration, Evaluation, Authorisation, and Restriction of Chemicals.[49] Yet chemicals/mixtures protected as CBI lack information regarding chemical structure, composition and biological activities, and access to analytical standards,[47] requiring innovative methods to determine hazardous chemical features within an unknown plastic chemical mixture, such as bioassay-guided chemical fractionation coupled with nontargeted analytical chemistry.[20,45] Such techniques are costly, however, and it remains unlikely that risks could ever be characterized with a high degree of certainty until full chemical compositions are known. Voluntary cooperation between industry and researchers in revealing the identity of some of these CBI chemicals provides a possible avenue for reducing such uncertainties.[50]

In addition to complicating the assessment of risk for chemicals and mixtures already present in the environment, protections provided by CBI may lead to the continued introduction of potentially hazardous chemicals into the environment.[51] For example, in 2018, the identities, quantities produced, location of production facilities, and other data for 396 new PFAS was withheld by manufacturers on the basis that such information is CBI.[52] Such confidential compounds may eventually be characterized years later using nontargeted analytical chemistry, as demonstrated by the recent discovery of a new class of chlorinated PFAS (apparently used as a substitute for other banned PFAS)[53]—chloroperfluoropolyether carboxylate compounds (ClPFPECAs).[54] Most concerning, ClPFPECAs are considered to be safe for use in polymerized nonstick cookware by the European Food Safety Authority[55]—despite their similarities to other PFAS, and a complete lack of publicly available toxicity information.[56] ClPFPECAs are unregistered in both the US EPA's and the European Chemical Agency's inventories.[56] It's possible that ClPFPECAs passed EPA's review without much, or any toxicity testing, as under TSCA (pre-2016 amendment), EPA was required to produce evidence for potential risk in order to investigate a chemical further[48,49]—a catch-22 that allowed 90% of chemicals entering commerce between 1979 and 2016 to evade restrictions or testing orders.[56]

The extremely diverse nature of microplastics is unparalleled; however, another emerging contaminant class may come relatively close and may provide insights for risk management. PFAS, like microplastics, are persistent, toxic, and largely unregistered in regulatory inventories.[46,57,58] The push to regulate PFAS in a timely manner has prompted some scientists and regulators to develop alternative methods to estimate their exposure and determine their hazards to estimate risk. A recent study estimated that there are over 4,700 PFAS chemicals distributed in the global market[59]—a multiplicity that makes developing analytical methods and determining toxicological effects for all constituents unachievable within reasonable timeframes. Novel, proxy-based approaches have been developed to estimate exposure (e.g., total fluorine),[60,61] and 21st century approaches are being applied to characterize hazards of PFAS (e.g., read-across).[62] Some of these approaches have proven, in some cases, to be health protective and simple, and are being considered for adoption by regulatory agencies.[63–65] While PFAS provide lessons for addressing extremely diverse and unique contaminant classes, microplastics are likely more complex and challenging (Box 2).

Box 2. Microplastics are a more complex contaminant class than PFAS

While many similarities exist between PFAS and microplastics (e.g., persistence, diversity, unknown composition, bioaccumulative potential, toxicity), there are principal differences between these contaminant classes which make understanding risks of microplastics arguably more challenging. The principal difference is that PFAS (with the exception of polymers and anions) are generally soluble,[66] while microplastics are (generally) insoluble[67]—thus having distinct physicochemical properties that may drive toxicological behavior as well as fate and transport characteristics—all of which are foundational in assessing exposure and risks. For other "conventional contaminants" (e.g., petroleum hydrocarbons), fate and transport characteristics are well studied.[68] Due to the diversity of the PFAS class and their unique characteristics (hydrophobic, lipophilic, and surfactant properties), traditional fate and transport models have proven inadequate in modeling their behavior—particularly in groundwater.[68,69] Even less understood are the environmental fate and transport behavior of microplastic particles, in which key determining factors are unique to insoluble particles (relatively less studied than soluble contaminants) and, in some cases, unique to synthetic polymers, such as: formation and emissions of microplastic particles; particle–particle interactions (e.g., aggregation and agglomeration); biological uptake and bioaccumulation; and transport via air and oceanic circulation.[70] Significant challenges for testing the toxicity of dispersed particles in aqueous systems remain,[71] and extrapolating effects of exposure at high concentrations to lower, environmentally relevant concentrations may not be appropriate.[70] Further challenges in assessing microplastics toxicity are the lack of standardized, environmentally realistic mixture samples, and the selection of natural particles as controls.[72] Finally, determining the drivers of microplastics toxicity (e.g., physical, chemical) is difficult,[73] as exemplified by the association of PFAS with plastic.[74]

unknown chemicals in Box 1).[45,46] Additionally, complex mixtures of chemicals on microplastics may exhibit mixture toxicity effects (i.e., additive, synergistic, antagonistic),[47] making their identification complicated.[20]

Plastics and PFAS are forever

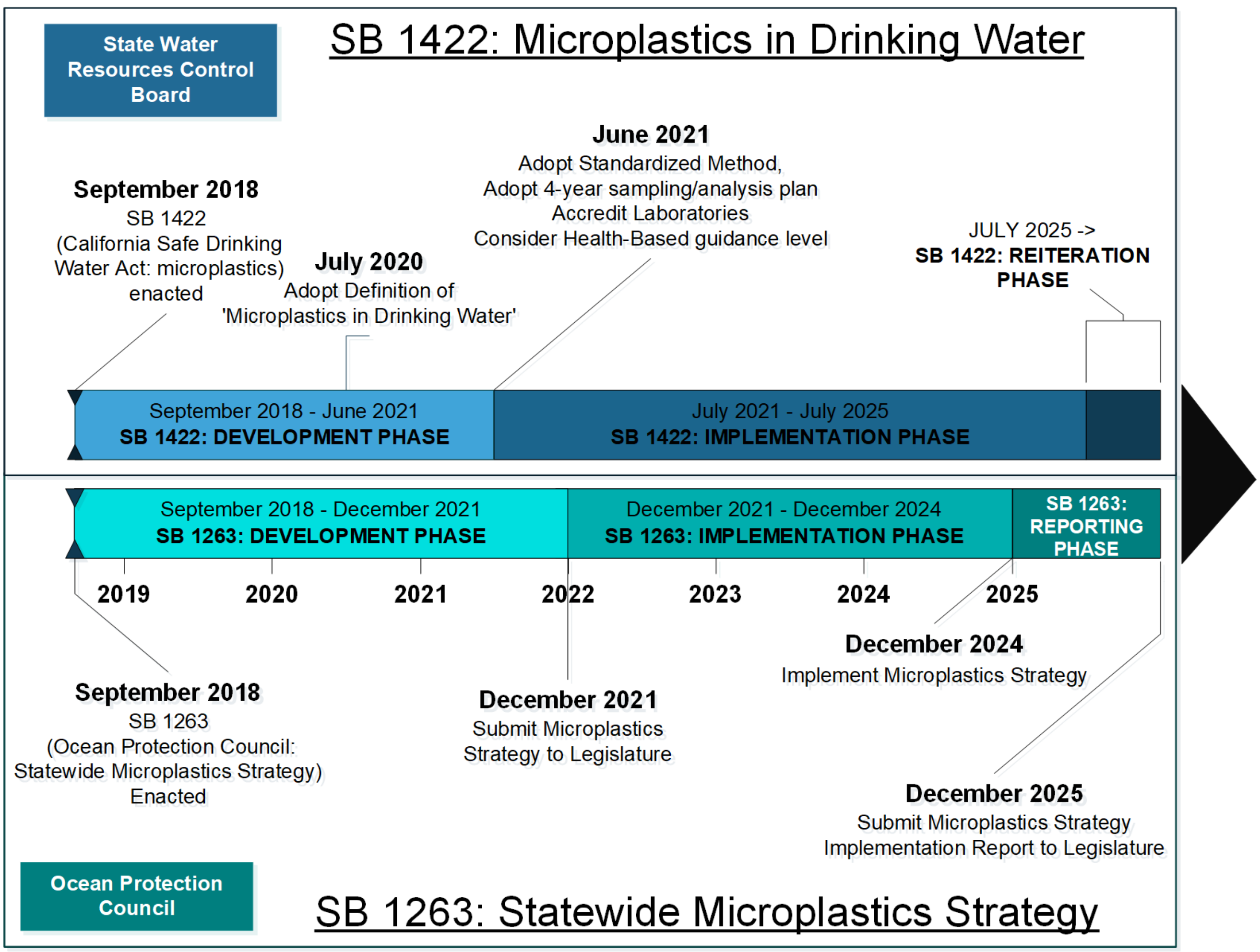
In an effort to prevent irreversible damage from persistent chemicals with poorly known effects, some regulatory agencies in Europe and the US have departed from their traditional risk-based frameworks. They are doing so by taking a more precautionary approach, classifying certain chemicals as "nonthreshold contaminants" (i.e., "any release to the environment and environmental monitoring data regarded as a proxy for an unacceptable risk").[75,76] A critical driver behind considerations of such precautionary management approaches is a chemical's ability to resist degradation in the environment (persistence)[77]—a trait which is shared by both microplastics and PFAS.[55,75] The combination of global environmental contamination, persistence, and uncertainties regarding effects on vital earth system processes satisfy the conditions for both PFAS and microplastics to be classified as "planetary boundary threats"—defined as factors that may irreversibly threaten the earth systems that allow humanity to thrive.[78,79] Indeed, PFAS are often referred to as "Forever Chemicals"—implying that their persistence should be worrying.[80]

In 2019, Denmark banned all PFAS (known and unknown) in paper and cardboard food contact materials.[81] This broad, class-based restriction was aimed at preventing widespread, irreversible environmental contamination of persistent, bioaccumulative, toxic chemicals within the PFAS class.[57] In managing PFAS, the concept of "essential use" is integral to drafting sensible, risk-based restriction regulations[82]—an approach which has been considered by the European Chemicals Agency in restricting the use of intentionally added microplastics,[75] and may also be useful in considering restrictions of single-use plastic products in a circular economy.

Like PFAS, microplastics are ubiquitous in the environment,[83] and some particle types are known to be toxic and bioaccumulative,[9,58] thus concerns over environmental persistence[84] are warranted.[85,86] With the continuous production and release of persistent chemicals, risk thresholds are likely to be exceeded over time, regardless of the chemical's properties.[77] This high likelihood of eventually exceeding risk thresholds renders traditional risk assessments inadequate, as they typically do not consider long-term impacts to future generations, or system-level effects at regional (or even global) scales.

The San Francisco Bay Regional Monitoring Program, which ranks contaminants of emerging concern monitored in water, sediment, and biota into tiered, risk-based categories (based on occurrence and hazard ratios),[76] initially classified microplastics as a constituent class of "Possible Concern" based on uncertainties regarding toxicity, but later elevated microplastics to "Moderate Concern," despite a noted lack of certainty regarding hazard thresholds.[87] The San Francisco Bay Regional Monitoring Program justified this departure from their established risk-based framework based on the EU's decision to classify microplastics as a nonthreshold

Figure 1. Timelines for implementation of California Senate Bills 1422 and 1263.



Requirements and timeline for implementation of recently passed California legislation aimed at advancing understandings of microplastics in drinking water (Senate Bill 1422) and in marine ecosystems (Senate Bill 1263). The California Ocean Protection Council, in collaboration with the State Water Resources Control Board, must implement requirements of Senate Bill 1263. The State Water Resources Control Board will implement requirements of Senate Bill 1422.

contaminant for risk assessment purposes;[75] uncertainties regarding toxicities;[87] an upward trend in both plastic production and environmental detection;[88–90] and persistence.[75,87] These decisions are in congruence with conclusions made by the Science Advice for Policy by European Academies, which state that while risk thresholds are exceeded at some locations (i.e., predicted or measured concentrations are greater than predicted no-effect levels), it is unlikely that exceedances of risk thresholds are geographically widespread;[12] however with expected increases in exposure to microplastics,[91] widespread ecological risk may arise within the next century.[12] In other words, while traditional regulatory frameworks typically focus on short-term risks from chemicals with known hazards, highly complex, persistent contaminants with unknown hazards are being recognized as potential irreversible global scale threats and are being precautionarily evaluated by regulators and scientists.

To meet unprecedented challenges in addressing perhaps the most complex, diverse, and publicly visibly contaminant suite (plastics pollution; including microplastics), California is partnering with an international network of researchers, local, state, and federal agencies, nongovernmental organizations, water purveyors, and engaged citizens.

A case study for intersector collaboration: California legislation as a regulation, policy, and science driver

California Senate Bills (SB) 1422 and SB 1263 outline initial steps to address microplastics in drinking water and the ambient marine environment, respectively.[26,27] In response to initial findings of widespread contamination of drinking water with microplastics[86] and considerable uncertainties regarding their health risks to humans at the time,[92] the California Legislature passed SB 1422 in 2018, which requires the State Water Resources Control Board (State Water Board) to adopt a definition for “microplastics in drinking water” by July 1, 2020 (see Box 3 for more), and to adopt a standard methodology for detecting microplastics in drinking water by July 1, 2021 (Fig 1). Additionally, the bill requires 4 years of testing and reporting of microplastics in drinking water, public disclosure of the results, and possible issuance of a health-based guidance level to interpret results.[26] SB 1263 requires the California Ocean Protection Council to adopt a statewide microplastics strategy (Strategy).[27] The Strategy shall include the development of standardized methods for sampling, detecting, and characterizing microplastics, development of a risk assessment framework for microplastics, and the use of that risk assessment framework to identify data gaps, and effective policy changes to reduce risks due to microplastic pollution in the ambient marine environment (Fig 1).[27]

To meet unprecedented challenges in addressing perhaps the most complex, diverse, and publicly visibly contaminant suite (plastics pollution; including microplastics), California is partnering with an international network of researchers, local, state, and federal agencies, nongovernmental organizations, water purveyors, and engaged citizens. For example, the California State Water Board has a long history of working with citizen scientists regarding characterizing trash and microplastics in water, reporting some of the earliest findings of persistent organic pollutants on preproduction plastics pellets along California’s beaches in 2005.[93] Starting in 2018, the California State Water Board began hosting annual, multiday, immersive “Trash Data Dives” where researchers (data scientists and trash/microplastic experts) work alongside municipalities, policy writers, regulators, nongovernmental organization leaders, community leaders, and others to develop a, “trash management picture informed by open and accessible data, to identify and understand trends, data gaps, and priorities.”[94] Similarly, the California Ocean Protection Council (which has made policy recommendations to reduce plastic pollution since 2007)[95] partnered with the National Oceanic and Atmospheric Administration in 2018 to develop the California Ocean Litter Prevention Strategy, which outlines actions that California and interested stakeholders can take to address ocean litter through 2024.[96] The Ocean Litter Prevention Strategy laid out critical needs in microplastics research, such as standardized methods, which were later included in SB 1263.[96]

Box 3. Lessons learned from PFAS in developing a regulatory definition for microplastics

After the discovery of some fluorinated chemicals in food contact materials (e.g., perfluoropolyether dicarboxylic acid) that were not formally recognized as PFAS under their definition at the time (-CnF2n +1-),[59,99] the Organisation for Economic Co-operation and Development (OECD) expanded their definition (-CnF2n-).[59] Meanwhile, other organizations (e.g., Interstate Technology Regulatory Council) more narrowly define perfluoroalkyl substances as having two or more fully fluorinated carbons (-CnF2n+1-), and polyfluoroalkyl substances as having a nonfluorine atom (typically hydrogen or oxygen) attached to at least one, but not all, carbon atoms, with at least two or more fully fluorinated carbons (-CnF2n+1-), with a further explicit exclusion of aromatic carbon ring substances.[66] In the case of extremely environmentally persistent chemicals like PFAS, the exclusion of certain chemicals from the contaminant class has resulted in a systematic lack of focus on their existence—resulting in sparse monitoring data (e.g., aromatic carbon ring PFAS).[100]

This debacle demonstrates the importance of starting with a broad definition as a common departure point for further definitions for microplastics and other emerging contaminant classes with significant uncertainties. Failure to start with a broad definition and consider all constituents within the class has resulted in the likely human exposure to short- (4 to 7 carbons) and ultrashort-chain (2 to 3 carbons) PFAS through food packaging in the US (e.g., 1,1,1,2-tetrafluoroethane, which is "generally recognized as safe" by the nation's Food and Drug Administration).[101] With regulatory agencies focused on long-chain PFAS (8+ carbons), industry has increased production of short and ultrashort alternatives,[102] even though they were included in the once commonly accepted definition of PFAS (-CnF2n+1-). Learning from mistakes made with PFAS, if regulatory definitions of microplastics are too narrow, risks may be underestimated due to their incomplete characterization and lack of consideration for the vast possibilities within the contaminant class.

A challenge in implementing California's legislative requirements to address microplastics in drinking water (SB 1422) was the apparent lack of a consensus definition for "microplastics." Despite calls for a unified, internationally agreed-upon definition for "microplastics,"[103] it seems that no such definition had emerged due (in part) to the lack of both standardized methods and regulations. Due to the regulatory impacts (i.e., monitoring and reporting and communicating health effects to consumers) associated with adopting a definition of microplastics in the context of drinking water, California's State Water Board recognized that the definition they adopted in June 2020 would likely be used for nondrinking water purposes and by other government agencies and scientific bodies.[104] In drafting an initial regulatory definition for microplastics (which have extreme uncertainties in regards to exposure and hazards for humans),[105] a principal consideration was to use terms that broadly encompass particle sizes (1 nm to 5 mm), types (e.g., theoretically soluble plastics), and polymers (e.g., including biodegradable polymers, for which limited toxicity information is available)[106] to avoid inappropriately restricting risk assessments based on regulatory definitions,[70] as well as research, monitoring, and collection of data—at least until the adoption of a more narrow definition can be justified.[31] Drawing lessons learned from PFAS, subcategories of microplastics may be grouped for strategic purposes for monitoring and regulations,[107] however should be distinguished from a broader class-based definition, with exclusions and limitations acknowledged wherever possible.[108]

In implementing SB 1422 and SB 1263, the California Ocean Protection Council and California State Water Board are collaborating with a wide range of stakeholders to accomplish the ambitious objectives required by the bills. The public research and development agency, the Southern California Coastal Water Research Project (SCCWRP) plays a pivotal role in the State's microplastics-related projects, coordinating more than 35 laboratories based in

7 different countries to standardize microplastics monitoring methods in aquatic environments, and serving as facilitator for the development of a consensus statement on the human health effects of microplastics in drinking water.[97] Additionally, the Ocean Protection Council is collaborating with an independent science-based nonprofit, The Ocean Science Trust, to convene an internationally recognized expert panel to develop a microplastics risk assessment framework as part of their Strategy.[98] Intersector working groups, such as the Pacific Northwest Consortium on Plastics and San Francisco Estuary Institute Microplastics Working Group, play key roles in coordinating local and regional research efforts that directly inform decision makers, and serve as exemplary models for constructive interactions between policymakers, scientists, regulators, and industry representatives.

Making microplastics research "actionable": Standardized methods and beyond

Scientific organizations have long called for the standardization of microplastic analysis methods;[109,110] the legislative requirements for California to adopt standard methodologies to monitor microplastics provides an impetus and requisite funding to develop such methods.[26,27] Standardization of microplastic monitoring methods will allow for direct comparisons between studies, may reduce uncertainties in assessments of risk, and reliably inform management strategies. It is important to keep in mind that unintended consequences may result if practical considerations of enacting regulations inhibit broader research investigations. For example, standardized methodologies may miss certain components (e.g. < approximately 10 µm particles, black particles) due to technical and economic barriers—a phenomenon that has caused a significant mismatch in the size ranges of particles used in toxicological assessments and monitored in the environment.[15] Therefore, as regulatory agencies adopt standardized methods for analyzing microplastics, the academic community should continue to improve detection methodologies,[111] and regulatory agencies should consider regularly updating their standardized methods.

In addition to developing standardized methods for monitoring microplastics in the environment, food, and water, further research is necessary to develop evidence-based policies and regulations. The policy and regulatory communities need actionable research that focuses on (a) addressing gaps in the understanding of the ecological and human health hazards and exposure of microplastics; (b) identifying and prioritizing sources (e.g., packaging, tire wear, textiles) and pathways (e.g., washing machines, stormwater, wastewater, biosolid agriculture application) that may be candidates for regulatory intervention; and (c) developing cost-effective technologies to reduce economic impacts of policy and regulatory interventions (e.g., analysis methods, water treatment, reusable or truly biodegradable materials). Moreover, quantitative toxicological risk assessments may be necessary under certain regulatory paradigms to effectively regulate microplastics as a water quality contaminant.[112] A useful strategy to accurately assess and convey risks associated with plastic without downplaying the potential of uncertain risks is to focus on known particle- and species-specific effect mechanisms (e.g., adverse outcome pathways).[112] These adverse outcome pathways allow for the separation of hazards of plastic-associated chemicals with the physical particles themselves,[112] allowing for a more simplistic understanding and communication of risks and development of risk-based regulations and policies. Most regulatory paradigms will prioritize high-risk microplastic morphologies—thus research should focus on reducing toxicological dimensions of complex mixtures to simplify sampling and monitoring plans.[32] Finally, research findings should be written so that they can be easily summarized and distilled into fact sheets and talking points, which are useful for both general media inquiries and policy briefings.

Conclusion

Microplastics as a contaminant class are unmatched in their magnitude of complexity, diversity, and persistence (with PFAS likely being the closest in all 3 categories), presenting significant challenges for scientists in developing analytical methods, fate and transport models, characterization of exposure pathways, and assessment of toxicological hazards. Considering unprecedented uncertainties associated with risks to humans and ecosystems, governmental organizations are reconsidering the appropriateness of applying traditional frameworks in mitigating risks of microplastics (and PFAS), opting in some cases for more precautionary approaches that give additional weight to uncertainties and environmental persistence. To address such challenging and complex emerging contaminant classes, governments should coordinate closely with researchers, citizens, industry representatives, and commercial monitoring laboratories, and should actively promote transparency, data accessibility, and civic engagement. California's pioneering efforts in addressing microplastics in drinking water and aquatic ecosystems serves as a model for developing open collaborations between diverse sectors.

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Superfund: EPA Should Take Additional Actions to Manage Risks from Climate Change

U.S. Government Accountability Office

Available federal data on flooding, storm surge, wildfires, and sea level rise suggest that about 60 percent (945 of 1,571) of all nonfederal National Priorities List (NPL) sites are located in areas that may be impacted by one or more of these potential climate change effects. These data, however, may not fully account for the number of nonfederal NPL sites that may be in such areas because (1) federal data are generally based on current or past conditions; (2) data are not available for some areas; and (3) the Fourth National Climate Assessment (NCA) has reported that climate change may exacerbate flooding, storm surge, and wildfires in certain regions of the United States. In addition, the Environmental Protection Agency (EPA) does not have quality information on the boundaries of nonfederal NPL sites, which could affect its ability to identify the number of sites that may be impacted by one or more of these potential climate change effects.

Available federal data suggest that 945 of 1,571 nonfederal NPL sites, or about 60 percent, are located in areas that may be impacted by selected climate change effects—that is, 0.2 percent or higher annual chance of flooding or other flood hazards, storm surge from Category 4 or 5 hurricanes, high and very high wildfire hazard potential, and sea level rise of up to 3 feet. The locations of these sites are shown in figure 1; the full results of our analysis and additional information on these sites is available in the interactive map and downloadable data file, which can be viewed at **https://www.gao.gov/products/GAO-20-73**.

Our analysis, however, may not fully account for the number of nonfederal NPL sites that may be impacted by the effects of climate change for various reasons. First, we represented the areas of nonfederal NPL sites based on a 0.2-mile radius around their primary geographic coordinates, which may not accurately reflect their area (i.e., they may be larger or smaller). We did not analyze site-specific information for these nonfederal NPL sites, including the extent of contamination and location of remedies. Such site-specific analyses would be needed to determine whether there is a risk to human health and the environment at nonfederal NPL sites as a result of these potential climate change effects.

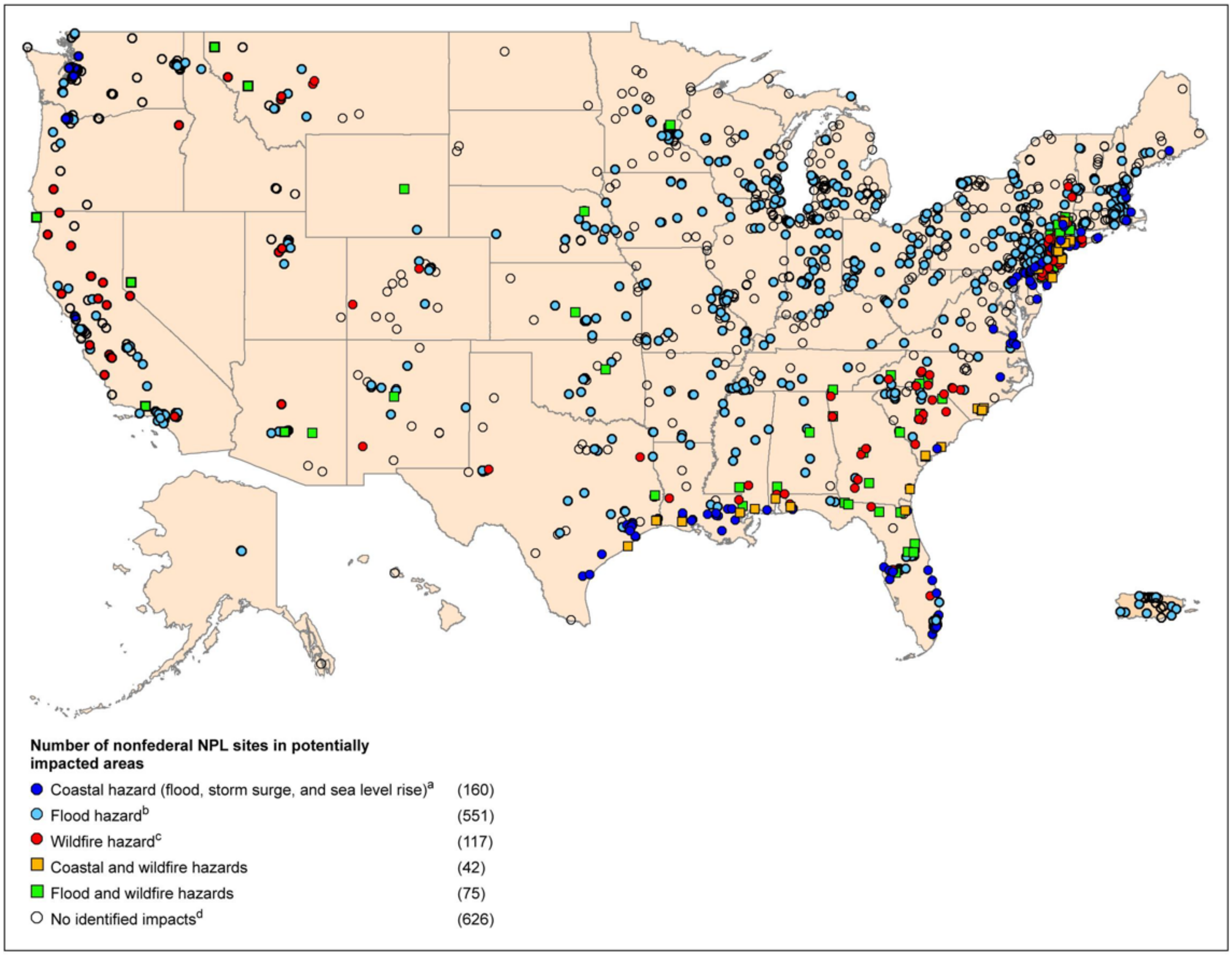
Further, according to the NCA, EPA documents, and interviews with EPA officials, there may be other climate change effects that could impact nonfederal NPL sites, such as potential increases in salt water intrusion (the movement of saline water into freshwater aquifers), drought, precipitation, hurricane winds, and average and extreme temperatures; we did not analyze these effects because we did not identify relevant national-level federal data sets.

Flooding

We identified 783 nonfederal NPL sites—approximately 50 percent—in areas that the Federal Emergency Management Agency (FEMA) had identified as having 0.2 percent or higher annual chance of flooding, which FEMA considers moderate flood hazard, or other flood hazards, as of October 2018.[1] Of these 783 sites, our analysis shows that 713—approximately 45 percent of all sites—are currently located in areas with 1 percent or higher annual chance of flooding, FEMA's highest flood hazard category. We provide information on the number of sites in areas with moderate or other flood hazards because, according to the NCA, heavy rainfall is

[1]Other flood hazards include areas with reduced risk because of levees as well as areas with flood hazard based on future conditions, for example, if land use plans were implemented. FEMA considers areas with at least 0.2 percent annual chance of flooding as having moderate flood hazard and those with 1 percent or higher annual chance of flooding to be Special Flood Hazard Areas (i.e., those with the highest chance of flooding).

Figure 1: EPA's Nonfederal NPL Sites in Areas That May Be Impacted by Flooding, Storm Surge, Wildfire, or Sea Level Rise

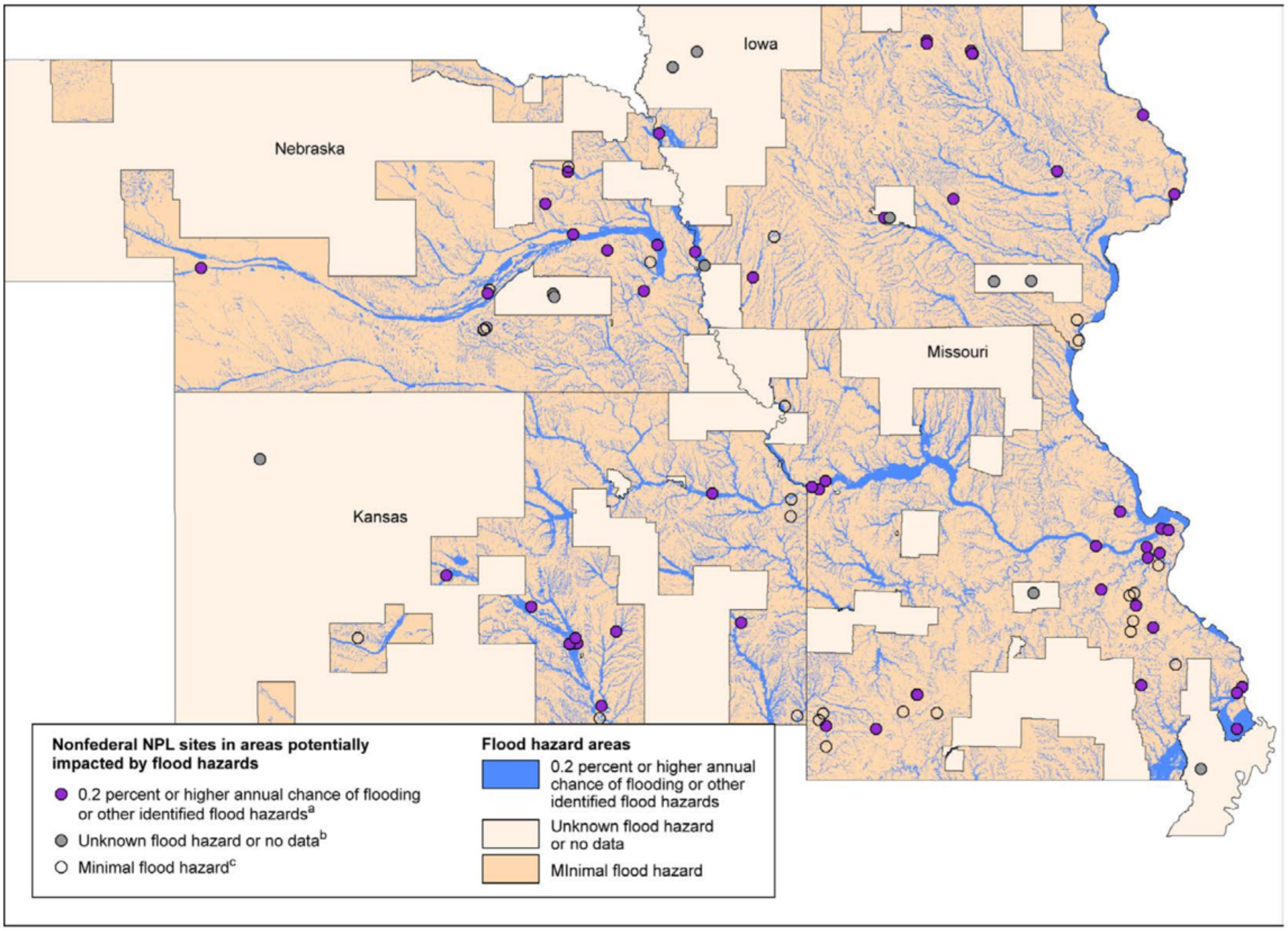


Sources: GAO analysis of Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA), and U.S. Forest Service data; MapInfo (map). | GAO-20-73

increasing in intensity and frequency across the United States and is expected to continue to increase, which may lead to an increase in flooding in the future. The full results of our analysis—which include information on the sites in areas that may have 1 percent or higher annual chance of flooding, 0.2 percent or higher annual chance of flooding or other identified flood hazards, unknown flood hazard or no data, and minimal flood hazard—are available in our interactive map, which can be viewed **here**. For example, there are a number of nonfederal NPL sites in EPA Region 7, where states experienced record flooding in early 2019. Specifically, as seen in figure 2, there are 51 sites that are located in areas with 0.2 percent or higher annual chance of flooding or other identified flood hazards, of which 42 are located in areas with 1 percent or higher annual chance of flooding.

Nationwide, the number of nonfederal NPL sites in areas that may be impacted by flooding currently may be higher than 783. Specifically, 217 nonfederal NPL sites are located in areas that FEMA has not assessed for flood hazards or that we did not analyze because the data were not available in a form we could use with our mapping software.

Figure 2: Nonfederal NPL Sites in EPA Region 7 Located in Areas That May Be Impacted by Flooding



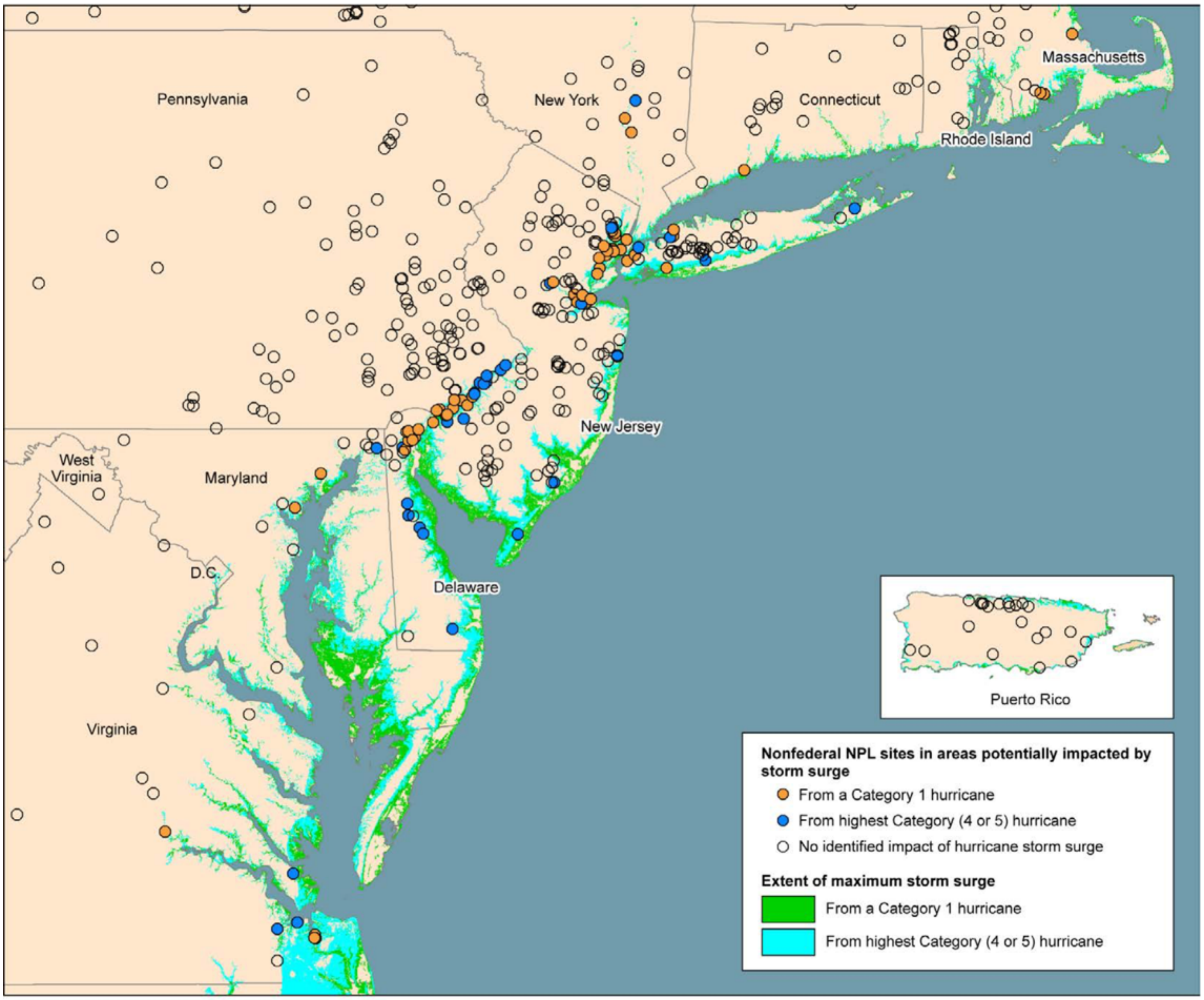
Sources: GAO analysis of Environmental Protection Agency (EPA) and Federal Emergency Management Agency (FEMA) data; MapInfo (map). | GAO-20-73

Storm Surge

We identified 187 nonfederal NPL sites—12 percent—in areas that may be inundated by storm surge corresponding to Category 4 or 5 hurricanes, the highest possible category, based on the National Oceanic and Atmospheric Administration's (NOAA) storm surge model as of November 2018.[2] Of these sites, 102 are located in areas that may be inundated by a storm surge corresponding to Category 1 hurricanes. We analyzed areas that may be inundated by a storm surge corresponding to the highest possible category because, according to the NCA, a projected increase in the intensity of hurricanes in the North Atlantic could increase the probability of extreme flooding because of storm surge along most of the Atlantic and Gulf Coast states, beyond what would be projected based solely on relative sea level rise. However, the NCA stated that there is uncertainty in the projected increase in frequency or intensity of Atlantic hurricanes, and other factors may affect the potential for flooding because of storm surge, such as changes in overall storm frequency or tracks. The full results of our analysis, which include information on the number of sites in areas that may be inundated by storm surge from Category 1 and from Category 4 or 5 hurricanes, are available in our interactive map, which can be viewed here. In EPA Regions 2 and 3, where states experienced damage from two major hurricanes in 2017, there are 87 nonfederal NPL sites located within areas that may be inundated by storm surge from Category 4 or 5

[2]According to a NOAA website, the model does not account for future conditions, such as erosion, subsidence (i.e., the sinking of an area of land), construction, or sea level rise.

Figure 3: Nonfederal NPL Sites in EPA Regions 2 and 3 Located in Areas That May Be Impacted by Storm Surge



Sources: GAO analysis of Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) data; MapInfo (map). | GAO-20-73

hurricanes.[3] Figure 3 shows these 87 sites, of which 54 sites may be inundated by storm surge from Category 1 hurricanes.

Nationwide, the number of nonfederal NPL sites in areas that may be impacted by storm surge may be higher than 187 because NOAA has not modeled areas along the West Coast and Pacific islands other than Hawaii.[4] Further, our analysis did not include other potential impacts from hurricanes, such as rainfall. Figure 4 shows an example of the impact of rainfall caused by a hurricane at the American Cyanamid NPL site.

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[3]Hurricanes Irma and Maria made landfall in Puerto Rico and the U.S. Virgin Islands in September 2017. These storms are considered among the five costliest hurricanes on record, according to FEMA.

[4]Our analysis may not accurately account for the impacts of storm surge because we included sites in areas that are protected by levees. NOAA officials told us that storm surge in these areas is difficult to model.

Figure 4: American Cyanamid National Priorities List Site—New Jersey

Overview: The American Cyanamid site is located in Bridgewater Township, New Jersey. Prior owners used the 575-acre site for chemical and pharmaceutical manufacturing operations for more than 90 years, resulting in the contamination of soil and groundwater from 27 unlined chemical waste lagoons and containment areas, or impoundments. Contamination includes volatile and semivolatile organic compounds and metals. EPA listed the site on the National Priorities List in 1983. Wyeth Holdings LLC, a subsidiary of Pfizer Inc., acquired the site in 2009 and assumed responsibility for its cleanup.

Site status in cleanup process: Cleanup of the site is ongoing. According to EPA's website and officials, EPA is treating contaminated soil, is installing caps over three highly contaminated impoundments and all site soils, and has constructed a new water treatment system to treat contaminated groundwater. EPA is in the process of designing the remedy for impoundments 1 and 2, which contain toxic acid tar, a residual by-product of refining coal light oil.

Potential impacts of climate change: According to our analysis, the site is located in an area that has a 1 percent or higher annual chance of flooding and may be impacted by storm surge from highest possible category hurricanes. In 2011, heavy rains from Hurricane Irene flooded the site, leading to, among other impacts, a loss of power and damage to a flood control berm. Impoundments 1 and 2, located about 700 feet from the Raritan River, also flooded, as seen in the picture (below left). After the floodwaters receded, EPA inspected the berm surrounding the impoundments and conducted water sampling. EPA concluded no significant release occurred.

Actions EPA has taken to manage risks to human health and environment from impacts of climate change: Since Hurricane Irene, EPA and the responsible party (i.e., Wyeth Holdings LLC) have taken additional actions to manage risks from flooding at the site, including reinforcing flood control berms, elevating electrical equipment 5 feet higher than flood levels resulting from Hurricane Irene, and, as seen in the picture (right), installing metal pillars to protect the elevated equipment from flood debris. In the 2018 record of decision for impoundments 1 and 2, because of, among other things, risk of future flooding, EPA chose to remove and treat the acid tar off-site.

Sources: GAO analysis of Environmental Protection Agency (EPA) information; EPA (left-hand photo); GAO (right-hand photo). | GAO-20-73

Wildfires

We identified 234 nonfederal NPL sites—15 percent—located in areas that have high or very high wildfire hazard potential—those more likely to burn with a higher intensity, based on a U.S. Forest Service model as of July 2018. For this analysis, we combined the high and very high wildfire hazard potential categories; we did not identify the number of sites in each of these categories separately. We did not analyze areas that currently have moderate or lower wildfire hazard potential because those with moderate or lower wildfire hazard potential are less likely to experience high-intensity wildfire and the extent to which wildfire hazard potential may change in the future is unknown. The full results of our analysis on the number of sites in areas with high or very high wildfire hazard potential are available in our interactive map, which can be viewed **here**. As seen in figure 5, there are 22 nonfederal NPL sites in areas with high or very high wildfire hazard potential in EPA Region 9, a region that experienced wildfires in 2018, including the highly destructive Carr Fire.[5]

Nationwide, the number of nonfederal NPL sites in areas that currently have high wildfire hazard potential may be higher than 234 because wildfire hazard data are only available for the contiguous United States (i.e., there are no data for Alaska, Hawaii and other Pacific islands, Puerto Rico, and the U.S. Virgin Islands). According to the NCA, the incidence of large forest fires in the western United States and Alaska has increased since the early 1980s and is projected to further increase in those regions as the climate changes. However, the NCA noted that analyses regarding the effect of climate change on the incidence of wildfire in other parts of the United States are not readily available, so it is unknown how climate change will affect the number of nonfederal NPL sites in areas rated with high or very high wildfire hazard potential nationwide. As figure 6 shows, wildfires can pose risks at nonfederal NPL sites, such as the Iron Mountain Mine site near Redding, California.

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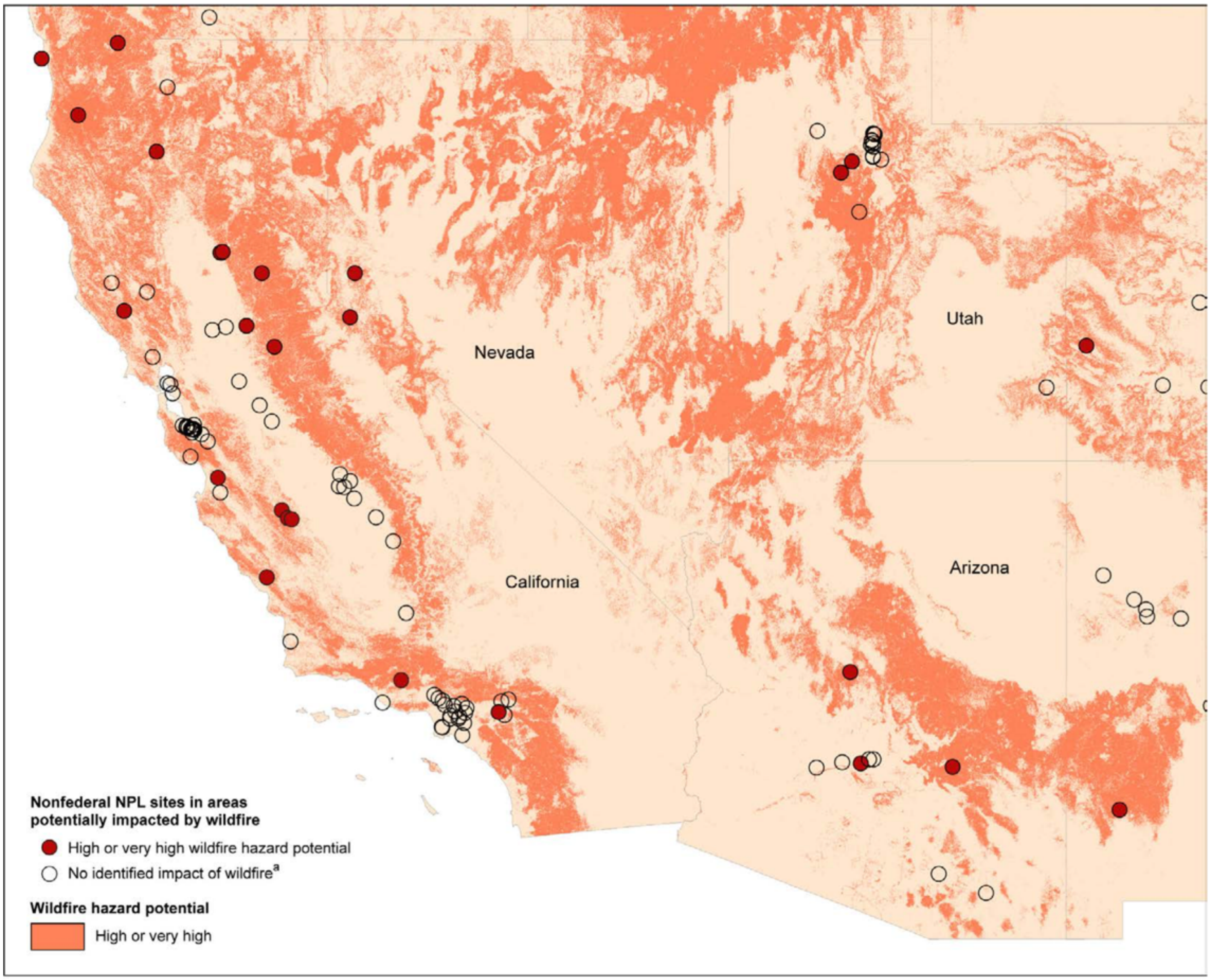
[5] The Carr Fire began on July 23, 2018, within the Whiskeytown National Recreation Area in Northern California, and by the time it was contained on August 30, 2018, it had covered approximately 229,651 acres and destroyed over 1,000 residences.

Figure 5: Nonfederal NPL Sites in EPA Region 9 Located in Areas with High or Very High Wildfire Hazard



Sources: GAO analysis of Environmental Protection Agency (EPA) and U.S. Forest Service data; MapInfo (map). | GAO-20-73

Sea Level Rise

We identified 110 nonfederal NPL sites—7 percent—located in areas that would be inundated by a sea level rise of 3 feet, based on our analysis of EPA and NOAA data as of March 2019 and September 2018, respectively. Our analysis shows that if sea level in these areas rose by 1 foot, 97 sites would be inundated. If sea level in these areas rose by 8 feet, 158 sites would be inundated. We also identified 84 nonfederal NPL sites that are located in areas that may already be inundated at high tide.[6] We provide the number of sites in areas that may be impacted by these sea level rise heights because, according to the NCA, global average sea levels are very likely to continue to rise by at least several inches in the next 15 years and by 1.0 to 4.3 feet by 2100. Further, the NCA states that a rise of as much as 8 feet by 2100 cannot be ruled out. The full results of our analysis, which include information on the number of sites in areas that may already be inundated at high tide and that would be

[6]These sites are located in areas at 0-foot sea level rise, which according to NOAA data is equivalent to the water level at the average of the highest of the two daily tides from 1983 to 2001.

Figure 6: Iron Mountain Mine National Priorities List Site—California

Overview: The 4,400-acre Iron Mountain Mine site near Redding, California, produced iron, silver, gold, copper, zinc, and pyrite through 1963. The underground mine workings and the fractured bedrock allow water and oxygen to react with the ore. The resulting acid mine drainage contains metals such as copper, cadmium, and zinc that are toxic to aquatic life, such as trout and salmon. EPA listed the site on the National Priorities List in 1983. In 2000, federal agencies and California reached a settlement with Aventis, the principal responsible party at the Iron Mountain Mine site. Global Loss Prevention, a wholly owned subsidiary of American International Group, operates the site.

Site status in cleanup process: Cleanup of the site is ongoing. EPA has constructed interim remedies, such as diverting streams to avoid contamination with acid mine drainage, and has begun a remedial investigation and feasibility study. According to EPA's sixth Five-Year Review report, in 2000, the potentially responsible party completed the construction of a water treatment system, seen in the picture, that captures most of the acid mine drainage, neutralizes it, and removes metals prior to discharge. The interim remedies remove 95 percent of the historic quantities of copper, cadmium, and zinc discharged from the Iron Mountain Mine and prevent uncontrolled releases of acid mine drainage into nearby streams and the Sacramento River in all but the most severe storms.

Potential impacts of climate change: According to our analysis, the site is located in an area with high or very high wildfire hazard potential. In July 2018, the Carr Fire burned through the site and almost destroyed the water treatment system. In the days that followed, fire was discovered in the high density polyethylene pipe that conveys acid mine drainage from one of the mines to the water treatment system. Firefighters, using specialized equipment, successfully extinguished the fire before it reached the ore body in the mine, which could have led to an explosion and substantial environmental and health hazards, according to an EPA report. EPA and state officials told us that increasing frequency and intensity of wildfires and landslides and erosion because of storm runoffs are an ongoing concern at the site.

Actions EPA has taken to manage risks to human health and environment from impacts of climate change: Following the fire, the site operator replaced portions of the pipes conveying acid mine drainage with nonflammable stainless steel, as can be seen in the bottom left corner of the picture. EPA officials told us that they plan to develop a model of water quality, including potential changing precipitation patterns because of climate change, in their remedial investigation for one of the operable units at the site.

Sources: GAO analysis of Environmental Protection Agency (EPA) information; GAO (photos). | GAO-20-73

inundated if sea level rose by 1 foot, 3 feet, and 8 feet, are available in our interactive map, which can be viewed **here**. There are 23 nonfederal NPL sites located within areas that may be impacted if sea level rose by up to 3 feet in EPA Region 6, a region that has experienced land loss because of sea level rise and coastal flooding, according to the NCA.[7] In addition, as seen in figure 7, 16—or 70 percent—of these sites may already be inundated at high tide.

Nationally, the number of nonfederal NPL sites that may be inundated by various heights of sea level rise will vary from the results of our analysis because different parts of the United States may experience higher or lower sea level rise than the global average. For example, the NCA states that sea level rise will be higher than the global average on the East and Gulf Coasts of the United States and lower than the global average in most of the Pacific Northwest and in Alaska. As can be seen in figure 8, sea level rise and other coastal hazards may impact nonfederal NPL sites, such as the one in the San Jacinto River Waste Pits site in Texas, parts of which are already under water.

EPA Does Not Have Quality Information on the Boundaries of Nonfederal NPL Sites

EPA does not have quality information on the boundaries of nonfederal NPL sites, which could affect its ability to identify the number of sites that may be impacted by one or more of these potential climate change effects.[8]

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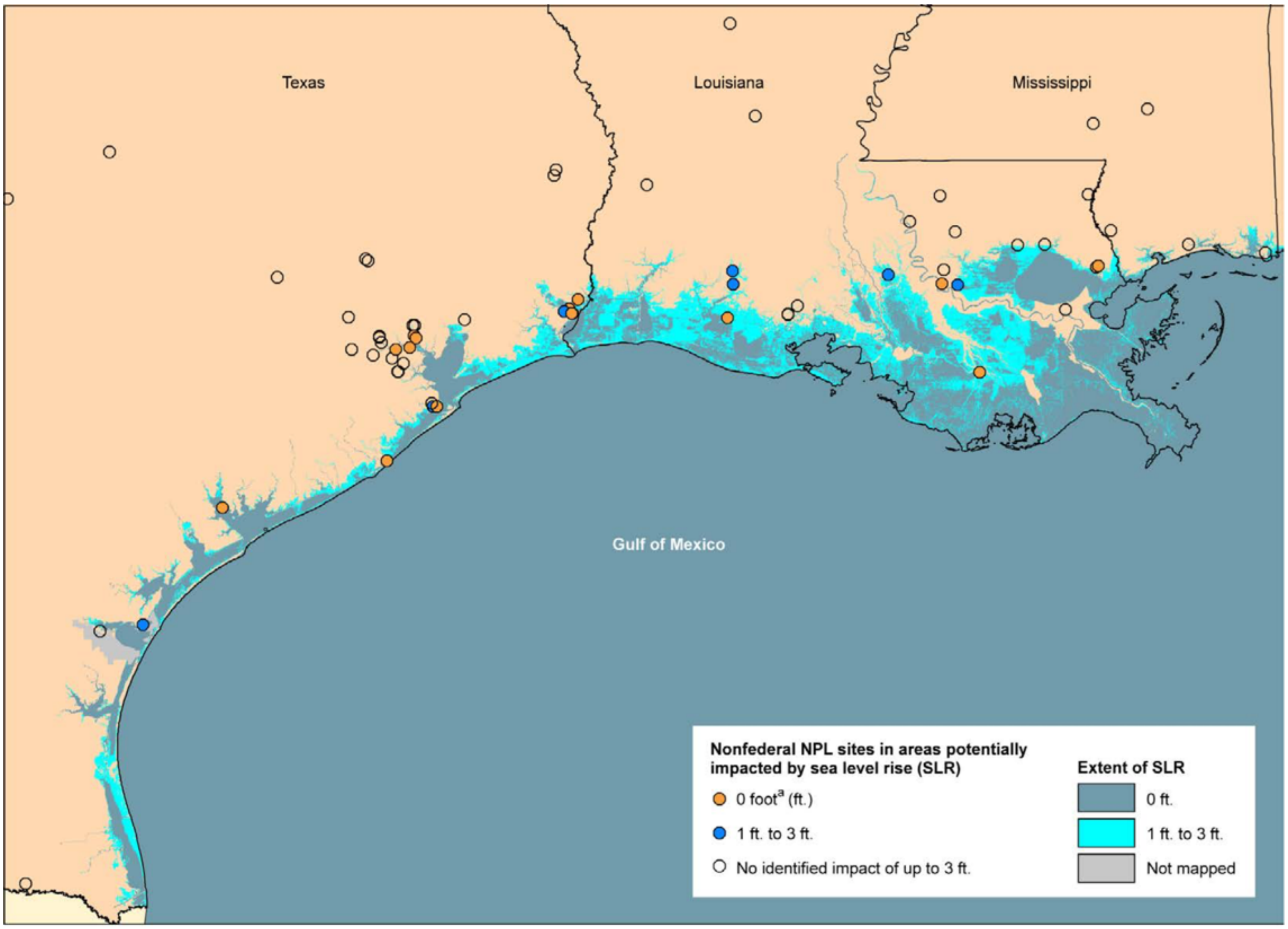
[7]There are 18 nonfederal NPL sites in EPA Region 6 that would be inundated if sea level rose by 1 foot. In addition, 28 nonfederal NPL sites would be inundated if sea level rose by 8 feet in that region.

[8]According to 2018 EPA guidance, site boundaries identify the geographic extent of the site as a whole, including areas of contamination, and those boundaries change over time. Environmental Protection Agency, Office of Land and Emergency Management, *Collection and Documentation of General Descriptive Geospatial Site Data*, Version 3.4 (May 2018).

Figure 7: Nonfederal NPL Sites in EPA Region 6 Located in Areas That Would Be Inundated by Sea Level Rise



Sources: GAO analysis of Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA) data; MapInfo (map). | GAO-20-73

According to EPA officials, EPA has not validated data on site boundaries and EPA's regional offices do not use a consistent geographic standard,[9] which makes it difficult to produce a national data set. In general, EPA officials told us that information on the boundaries of NPL sites has not been a focus at a national level and is not yet subject to quality standards. For example, EPA officials told us that boundary information for each NPL site represents the remedial project manager's professional judgment and remedial project managers may determine and record the boundaries of sites differently.

EPA has taken some initial actions to improve the quality of information on the boundaries of nonfederal NPL sites. In November 2017, the Office of Superfund Remediation and Technology Innovation issued a directive to all regional Superfund division directors recommending national standards for collecting and maintaining geographic information, including site boundaries.[10] EPA's 2017 directive notes that using national standards to

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[9]Geographic standards include, for example, using the same geodetic datum, which, according to a NOAA website, uses a reference surface (such as sea level) to provide known locations to begin surveys and create maps. See https://www.ngs.noaa.gov/datums/index.shtml, accessed on July 26, 2019.

[10]Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation, *Memo on Geospatial Superfund Site Data Definitions and Recommended Practices*, OLEM Directive 9200.2-191 (Nov. 29, 2017).

Figure 8: San Jacinto River Waste Pits National Priorities List Site—Texas

Overview: The approximately 40-acre San Jacinto River Waste Pits site is located east of Houston, Texas, between two unincorporated areas known as Channelview and Highlands. In the mid-1960s, liquid and solid pulp and paper mill wastes were disposed of at the site in impoundments, or waste disposal areas. The primary hazardous substances at the site, by-products of the pulp bleaching process, are dioxins and furans, exposure to which can cause several health effects, including skin diseases and liver damage. Added to the National Priorities List in 2008, the site consists of impoundments in and adjacent to the San Jacinto River north and south of Interstate 10. As seen in the picture, the San Jacinto River covers part of the northern impoundment, the boundaries of which are marked with buoys. The International Paper Company and McGinnes Industrial Maintenance Corporation are responsible for the cleanup.

Site status in cleanup process: Cleanup of the site is ongoing. In 2010, EPA required the potentially responsible parties to, among other things, install and maintain a temporary armored cap over the waste that could withstand storm events with 1 percent or higher annual chance of occurring. The temporary armored cap includes an impervious geomembrane under the northern impoundment and a cover over the impoundment. The potentially responsible parties also stabilized and solidified part of the paper mill waste. EPA is currently designing the long-term remedy for the site.

Potential impacts of climate change: According to our analysis, the site is located in an area that has a 1 percent or higher annual chance of flooding and that may be impacted by storm surge from Category 1 hurricanes and sea level rise of 0 foot. According to the 2017 record of decision, since the installation of the temporary cap, EPA has observed repeated damage to sections of the cap, including in September 2017 from Hurricane Harvey. Record-breaking rainfall during the hurricane led to flooding, which eroded the cap in some places, exposing some of the contaminated material. EPA detected high levels of dioxins in one area it sampled.

Actions EPA has taken to manage risks to human health and environment from impacts of climate change: According to the operations, monitoring, and maintenance plan of the time-critical removal action for the site, EPA has directed the potentially responsible parties to periodically inspect the cap and conduct repairs as needed after certain flood events. In the 2017 record of decision, EPA required the potentially responsible parties to remove and treat most of the contaminated material off-site, because of, among other things, risk of future flooding from hurricanes and sea level rise.

Sources: GAO analysis of Environmental Protection Agency (EPA) information; GAO (photo). | GAO-20-73

collect geographic information, including site boundaries, promotes EPA's reporting and analytical efforts to support program implementation and evaluation. In addition, in May 2018, EPA's Office of Land and Emergency Management developed technical guidance for all its regions and programs for collecting, documenting, and managing geographic information on Superfund sites, including their boundaries.[11] EPA officials told us that in 2019 and 2020, the agency plans to move toward recording site boundaries in a consistent format across regions and instituting procedures to validate and update them at least annually.

However, EPA officials told us that there is no schedule in place for completing this effort and they are uncertain when they will complete it because of competing priorities. By developing a schedule for completing the standardization and improvement of the quality of the information on the boundaries of nonfederal NPL sites, EPA could more reasonably ensure that it would have quality information with which to fully identify nonfederal NPL sites that are located in areas that may be impacted by climate change effects.

Recommendations for Executive Action

GAO is making four recommendations to EPA, including that it clarify how its actions to manage risks at nonfederal NPL sites from potential impacts of climate change align with current goals and objectives. EPA agreed with one recommendation and disagreed with the other three. GAO continues to believe that all four are warranted. The recommendations are as follows:

1) The Director of the Office of Superfund Remediation and Technology Innovation should establish a schedule for standardizing and improving information on the boundaries of nonfederal NPL sites.
   - *Status:* In its June 2020 response, EPA stated that it had convened a working group comprising of Superfund and regional officials to collect and disseminate geospatial information for all NPL sites to help EPA analyze, communicate, and respond to the impacts of natural disasters and weather. EPA has not, however, provided a schedule for completing this effort.

[11]Environmental Protection Agency, Office of Land and Emergency Management, Collection and Documentation of General Descriptive Geospatial Site Data, Version 3.4 (May 2018).

2) The Administrator of EPA should clarify how EPA's actions to manage risks to human health and the environment from the potential impacts of climate change effects at nonfederal NPL sites align with the agency's current goals and objectives.

   - *Status:* In June 2020, EPA stated that it agreed with the recommendation but did not plan to take any action to respond to it because it believed its actions are aligned with agency goals and objectives. In April 2021, EPA stated that it is considering whether to take action responsive to the recommendation. We continue to believe that clarifying this alignment to the agency's current goals and objectives is warranted.

3) The Director of the Office of Superfund Remediation and Technology Innovation should provide direction on how to integrate information on the potential impacts of climate change effects into risk assessments at nonfederal NPL sites.

   - *Status:* In June 2020, EPA stated that it would issue a memorandum that would provide direction on integrating information on the potential impacts of climate change effects into risk assessments at nonfederal NPL sites in the fourth quarter of fiscal year 2020. In April 2021, EPA stated that this memorandum is now expected to be released in May 2021. At that time, we will review the memorandum to determine if it is responsive to our recommendation.

4) The Director of the Office of Superfund Remediation and Technology Innovation should provide direction on how to integrate information on the potential impacts of climate change effects into risk response decisions at nonfederal NPL sites.

   - *Status:* In June 2020, EPA stated that it would issue a memorandum that would provide direction on integrating information on the potential impacts of climate change effects into risk response decisions at nonfederal NPL sites in the fourth quarter of fiscal year 2020. In April 2021, EPA stated that the memorandum is now expected to be released in May 2021. At that time, we will review the memorandum to determine if it is responsive to our recommendation.

News and Announcements

Renewable Natural Resources Foundation

Upcoming Virtual Round Table: Sustainably Managing California's Groundwater in the Midst of a Prolonged Drought

Register Here

June 9, 2021

1:00 – 2:00 PM (ET)

Online Webinar

RNRF is pleased to welcome Ellen Hanak, vice president of the Public Policy Institute of California and director of the PPIC Water Policy Center, to speak at the Washington Round Table on Public Policy.

California, a historically dry state, experienced one of its worst periods of drought on record between 2012 and 2016. During times like these, the state tends to rely on its groundwater reserves more than normal, especially to support its large agricultural sector. This has led to the steady depletion of California’s groundwater, causing problems like land subsidence in the San Joaquin Valley and drinking water wells going dry. In response to this problem, California enacted the Sustainable Groundwater Management Act in 2014. This law aims to achieve sustainable groundwater management in California by the early 2040s. Now, as California is entering another drought, the act is being put to its first major test.

Hanak will speak about the imbalance between supply and demand for water in California as it relates to drought, climate change, and agricultural production, and the consequences for groundwater sustainability. She will also discuss challenges to the early stages of the Sustainable Groundwater Management Act’s implementation in the context of California’s current drought.

Under Hanak's leadership, the PPIC Water Policy Center has become a critical source of information and guidance for natural resource management in California. Her other areas of expertise include climate change and infrastructure finance. Previously, she served as research director at PPIC. Before joining PPIC, she held positions with the French agricultural research system, the President’s Council of Economic Advisers, and the World Bank. She holds a PhD in economics from the University of Maryland.

The round table will be conducted virtually via Zoom Webinars. Once registered, and in advance of the event, you will receive a link and instructions for joining the webinar.

Now Accepting Nominations for RNRF’s 2021 Awards Program

RNRF is now accepting nominations for its 2021 Awards Program.

The **Sustained Achievement Award** recognizes a long-term contribution and commitment to the protection and conservation of natural resources by an individual.

The **Outstanding Achievement Award** recognizes a project, publication, piece of legislation, or similar concrete accomplishment that occurred during the three years prior to nomination for the award.

The **Excellence in Journalism Award** honors and encourages excellence in print journalism about natural resources, recognizes work by an individual, group, or organization for both print and digital media.

Nominations will be accepted until June 1, 2021.

For more information on selection criteria, eligibility, and submission instructions, visit the **Call for 2021 Awards Nominations.**

For more information on RNRF's Awards Program and lists of past winners, visit RNRF's **Awards Program page.**

American Meteorological Society

102nd AMS Annual Meeting

23-27 January 2022

Houston, Texas

Planning is underway for the 2022 AMS Annual Meeting to be held 23–27 January 2022 in Houston, Texas at the George R. Brown Convention Center.

We are excited about how our theme for this 102nd Annual Meeting: "Environmental Security: Weather, water, and climate for a more secure world" has come together thanks to the hard work of the Overall Planning Committee, John Lanicci and Gina Eosco (co-chairs), Andrea Bleistein, Roger Pulwarty, and Eileen Shea.

For more information, click **here**.

American Society of Civil Engineers

ASCE 2021 Convention

6-8 October, 2021

Virtual

The ASCE Convention is the Society's flagship membership event. It is the single annual opportunity that the entire Society is represented together and reflects the diversity of civil engineering that ASCE encompasses. The program for the Convention will be of an integrated, cross-cultural, technical, and educational nature.

For more information, click **here**.

American Society of Landscape Architects Fund

ASLA Congratulates New Interior Secretary on her Historic Confirmation

On March 15, then-Representative Deb Haaland (NM) was confirmed by the U.S. Senate to become the U.S. Secretary of the Interior and was sworn into office on the following day. Her nomination and confirmation are historic in nature. Sec. Haaland, a 35th generation New Mexican and enrolled member of the Laguna Pueblo Tribe, is the first ever Native American cabinet secretary.

On March 17, the New Mexico Chapter of ASLA and government affairs staff **sent a letter** to Sec. Haaland congratulating her on her confirmation and providing insight on climate change, natural and cultural resources, and outdoor recreation policies for our public lands. ASLA National followed up with **our own letter** of congratulations, with an offer to work with the Secretary and DOI staff on issues of mutual importance. This is in addition to ASLA sharing a **comprehensive set of policy recommendations** with the administration.

To read more, click **here**.

American Water Resources Association

WEBINAR: What Does Water Justice Require of You?

23 June, 2021

Virtual

The Biden administration has shifted the focus of environmental and natural resources policy toward environmental justice in a startling and profound manner. The water sector will benefit from a substantial flow of new resources, but those resources will be conditioned on better serving marginalized communities and satisfying the demands of environmental justice. This webinar will explore the practical implications of this paradigmatic shift for water resources professionals.

For more information, click **here**.

Geological Society of America

Plastic Pollution in the Deep Sea: A Geological Perspective

Boulder, Colo., USA: A new focus article in the May issue of Geology summarizes research on plastic waste in marine and sedimentary environments. Authors I.A. Kane of the Univ. of Manchester and A. Fildani of the Deep Time Institute write that “Environmental pollution caused by uncontrolled human activity is occurring on a vast and unprecedented scale around the globe. Of the diverse forms of anthropogenic pollution, the release of plastic into nature, and particularly the oceans, is one of the most recent and visible effects.”

The authors cite multiple studies, including one in the May issue by Guangfa Zhong and Xiaotong Peng, discussed in a previous **GSA press release** when it was published online ahead of print (26 Jan. 2021). Zhong and Peng were surprised to find plastic waste in a deep-sea submarine canyon located in the northwestern South China Sea.

To read more, click **here**.

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