United States Government Accountability Office

Report to Congressional Requesters

June 2022

WATER QUALITY

Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia

GAO-22-104449

GAO Highlights

Highlights of GAO-22-104449, a report to congressional requesters

June 2022

WATER QUALITY

Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia

Why GAO Did This Study

Harmful algal blooms—overgrowths of algae in water bodies—can produce toxins that harm humans and animals. These blooms are an environmental problem in all 50 states, according to EPA. Harmful algal blooms are also associated with some occurrences of hypoxia—depleted oxygen levels in a water body in which most animals cannot survive. Hypoxia can harm fisheries and disrupt ecosystems.

Under the act, the interagency working group, with NOAA and EPA leadership, is to maintain and enhance a national harmful algal bloom and hypoxia program, develop a comprehensive research plan and action strategy, and submit various reports to Congress.

GAO was asked to review federal efforts to manage harmful algal bloom and hypoxia risks. This report examines, among other things, (1) working group efforts to implement a national program; (2) agencies' actions to monitor and forecast harmful algal bloom and hypoxia events; and (3) agencies' actions to help state, local, and tribal governments respond to these events. GAO examined agency and working group documents and interviewed federal, state, local, and tribal officials with experience in responding to these events.

What GAO Recommends

GAO is making six recommendations, including that NOAA and EPA define a national program and develop a national goal for prevention actions, and that EPA develop frameworks to expand freshwater monitoring and forecasting. NOAA and EPA agreed with GAO's recommendations.

View GAO-22-104449. For more information, contact Alfredo Gómez at (202) 512-3841 or gomezj@gao.gov.

What GAO Found

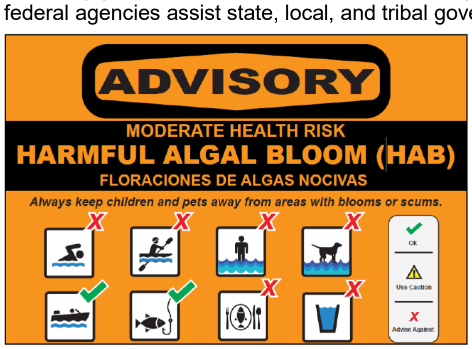
The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, as amended, led to the establishment of a federal interagency working group to help address these environmental issues. The working group is co-chaired by the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA). The working group has developed a national research plan and action strategy, as well as subsequent progress reports and other planning documents to guide its efforts, but it has not implemented a national program under the act. Consistent with leading program management practices, an important next step will be to define what such a program would entail. By doing so, the group would be better positioned to implement the program and enhance federal efforts to manage the risks of harmful algal blooms and hypoxia.

Federal agencies in the working group have taken actions to monitor and forecast harmful algal bloom and hypoxia events in some coastal regions and marine waters of the U.S. but have done less for inland freshwater bodies. NOAA has developed a framework to expand monitoring and forecasting of events in marine waters and the Great Lakes. However, EPA has not done the same for other freshwater bodies, in part because of the large number of inland freshwater bodies that exist. By developing interagency frameworks to expand freshwater monitoring and forecasting, EPA and the working group would be better positioned to manage the risks of such events.

Federal agencies in the working group have taken actions to help state, local, and tribal governments respond to harmful algal bloom and hypoxia events (see fig.). In addition, the working group and others have identified a need for more actions aimed at preventing these events. However, the group does not have a national goal to help focus agencies' efforts on prevention. By developing such a goal, the working group, led by NOAA and EPA, could help to increase federal attention on actions to prevent these events.

Harmful Algal Bloom Advisories Posted by States

Providing guidance to inform decisions on posting public health advisories is one of the ways that federal agencies assist state, local, and tribal governments.



Sources: New Jersey Department of Environmental Protection (left) and Oregon Department of Agriculture (right). | GAO-22-104449

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Abbreviations

CDC	Centers for Disease Control and Prevention
CyAN	Cyanobacteria Assessment Network
EPA	Environmental Protection Agency
HAB	harmful algal bloom
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OIG	Office of Inspector General
TMDL	total maximum daily load
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

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Congressional Requesters

Harmful algal blooms (HAB)—overgrowths of algae in marine waters and freshwater bodies—are a major environmental problem in all 50 states, according to the Environmental Protection Agency (EPA). HABs can produce toxins that can harm humans, animals, and the environment. HABs can also close beaches, raise treatment costs for drinking water, reduce property values, and decrease the catch from both recreational and commercial fisheries.[1] For example, a 2018 HAB event near Salem, Oregon, led the city to issue drinking water advisories and build a $48 million drinking water treatment facility, among other investments, to help protect against HABs. Algae overgrowth is also associated with some occurrences of hypoxia—low or depleted oxygen levels in a water body in which most animals cannot survive—that can harm fisheries and disrupt ecosystems.[2]

The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, as amended, governs a number of specific federal activities to address HABs and hypoxia.[3] The act calls for the establishment of an interagency task force on HABs and hypoxia, which its member agencies generally refer to as "the working group." Under the act, the working group is to, among other things, maintain and enhance a national marine and freshwater HAB and hypoxia program, develop a comprehensive research plan and action strategy, and develop and submit various

[1]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report* (Washington, D.C.: Feb. 11, 2016); and *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation* (Washington, D.C.: Mar. 5, 2018).

[2]Hypoxia is a condition where low dissolved oxygen in aquatic systems causes stress or death to resident organisms. 33 U.S.C. § 4008(4). Low or zero oxygen conditions occur in water bodies because of the confluence of physical, chemical, and biological processes. HABs also can exacerbate hypoxic events and, concurrently, hypoxia can promote HABs by increasing phosphorus release from sediments.

[3]Pub. L. No. 105-383, tit. VI, 112 Stat. 3447 (codified as amended at 33 U.S.C. §§ 4001-4010). Other laws, such as the Water Resources Development Act of 2020, have also addressed federal activities related to HABs and hypoxia.

reports and assessments to Congress.[4] The working group is also tasked with helping state, local, and tribal governments manage the risks of both marine and freshwater HAB and hypoxia events.[5] According to working group reports, HABs and hypoxia occur naturally, but their prevalence, frequency, and severity are increasing.[6] This increase is influenced by excess nutrients from sources such as agricultural and wastewater runoff, as well as invasive species, climate change, atmospheric pollution, and other ecological changes, according to the reports.

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and EPA are the working group co-chairs.[7] The 18 other member agencies of the working group are

- the Department of Agriculture's Agricultural Research Service, National Institute of Food and Agriculture, and Natural Resources Conservation Service (NRCS);
- the Department of Defense's Department of the Navy and U.S. Army Corps of Engineers;

[4]The act provides that the National Oceanic and Atmospheric Administration is to have primary responsibility for administering the national HAB and hypoxia program, except with respect to the freshwater aspects of the program, for which EPA is to have primary responsibility. 33 U.S.C. § 4002(d), (h).

[5]In addition, amendments to the act enacted in 2019 authorized NOAA and EPA to make federal funds available to affected states or local governments upon a determination that there is a HAB or hypoxia event of national significance. Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2017, Pub. L. No. 115-423, § 9(g), 132 Stat. 5462, 5463 (2019) (codified at 33 U.S.C. § 4010). The act defines an event of national significance as a HAB or hypoxia event that has had or will likely have significant environmental, economic, subsistence use, or public health impact on an affected state. *Id.* NOAA and EPA are working to develop policies for determining when HAB or hypoxia events are events of national significance, according to agency officials.

[6]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report;* and *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*.

[7]The White House Office of Science and Technology Policy is also identified in working group documentation as an additional co-chair that provides oversight of the group's direction and activities, publishes documents produced by the working group, and submits such documents to Congress. However, as of October 2021, there was no official co-chair representative from the office serving on the working group. According to officials from this office, NOAA and EPA are the key implementers of the working group's activities and would take the lead on implementing any improvements to the group that are needed in the future.

- the Department of Health and Human Services' Centers for Disease Control and Prevention (CDC), Food and Drug Administration, and the National Institute of Environmental Health Sciences;
- the Department of Homeland Security's Coast Guard;
- the Department of the Interior's Bureau of Indian Affairs, U.S. Fish and Wildlife Service, National Park Service, and U.S. Geological Survey (USGS);
- the National Aeronautics and Space Administration (NASA);
- the National Science Foundation;
- the State Department; and
- the White House Council on Environmental Quality and Office of Science and Technology Policy.

We previously reported that, since 2014, the working group has been the primary, government-wide mechanism through which federal agencies coordinate their activities, develop plans for future work, and identify remaining gaps related to federal HAB activities and capabilities.[8] In addition, we found that 12 federal agencies had spent approximately $101 million on HAB-related activities, such as research and monitoring, from fiscal years 2013 through 2015.

More recently, you asked us to review federal efforts to manage the risks of HABs and hypoxia. This report examines (1) the extent to which the working group has implemented a national HAB and hypoxia program and assessed the results of federal efforts to manage the risks of HABs and hypoxia; (2) actions that federal agencies in the working group have taken to monitor and forecast HAB and hypoxia events; and (3) actions that federal agencies in the working group have taken to help state, local, and tribal governments respond to HAB and hypoxia events.

For all three objectives, we reviewed relevant laws, analyzed agency and working group documents related to HAB and hypoxia initiatives, and interviewed officials from most member agencies of the working group. We also interviewed selected stakeholders from nongovernmental

[8]GAO, *Environmental Protection: Information on Federal Agencies' Expenditures and Coordination Related to Harmful Algae,* GAO-17-119 (Washington, D.C.: Oct. 14, 2016).

organizations, water sector groups, and academia whom we identified through a targeted internet search and snowball sampling approach.[9]

To address our second and third objectives, we also conducted seven small group discussion sessions with state officials who have been involved in managing their state's response to HABs and hypoxia. Through these discussion groups, we spoke with officials from 37 states about their experiences working with federal agencies on issues related to HABs and hypoxia, including challenges and opportunities for further federal action. We cannot generalize the information obtained through these sessions to other states that did not participate, but we analyzed the information from the small group discussions for common themes and illustrative examples. In addition, as part of addressing our third objective, we interviewed officials from selected local and tribal governments. We selected these officials for interviews based on recommendations from state officials who participated in our discussion groups and to reflect geographic diversity. For further details on our objectives, scope, and methodology, see appendix I.

We conducted this performance audit from September 2020 to June 2022 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Every state in the U.S. has experienced some kind of HAB or hypoxia event, in many cases annually, according to a report by the working group.[10] Most algae are not harmful but are natural components of marine and freshwater flora, and the proliferation of algae generally provides the energy source to fuel food webs. However, some types of algae can grow out of control or produce toxins within their cells. When certain conditions are present, these algae can multiply rapidly, causing "blooms" and

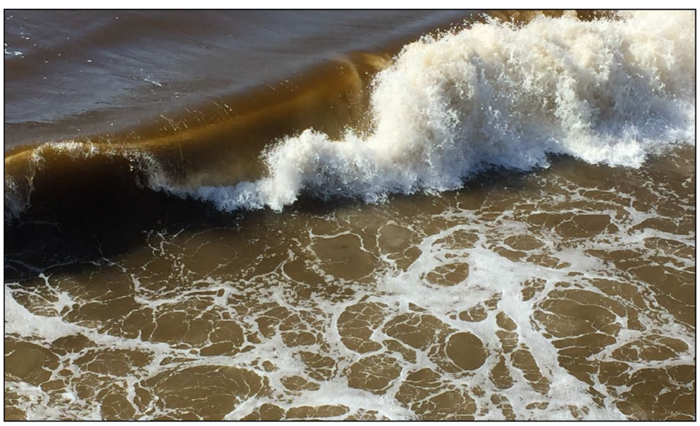
[9]Through the snowball sampling approach, we asked representatives of each stakeholder organization to propose or recommend additional stakeholders for us to interview.

[10]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report*.

increasing the risk of cells producing and releasing toxins into water bodies.[11]

Different regions of the country contain diverse organisms that can cause different types of HABs in fresh, marine, and brackish (a mixture of fresh and salt) water bodies, according to NOAA. Depending on the type of organism, blooms can be any number of colors or can be colorless.[12] For example, some marine organisms can discolor the water different shades of red and brown, creating "red tides." In contrast, cyanobacteria, a type of bacteria commonly referred to as "blue-green algae," are frequently found in freshwater systems and can make the water appear bright green or blue-green (see fig. 1). Moreover, some algal blooms in fresh, marine, and brackish water bodies produce highly potent toxins, known as algal toxins, according to USGS officials. The toxins produced by cyanobacteria are called cyanotoxins.

Figure 1: Different Organisms Cause Different Color Changes During Marine and Freshwater Algal Bloom Events



Sources: Lanna Cheng, University of California San Diego/Scripps Institution of Oceanography (left) and Kansas Department of Health and Environment (right). | GAO-22-104449

Note: Photo on the left is of a 2020 "red tide" event in La Jolla Shores, California. Photo on the right is of a harmful algal bloom in Milford Lake, Kansas.

[11]According to USGS officials, improving understanding of the factors that cause toxic HABs is an active area of research.

[12]Colorless toxins can still be in the water after visible blooms have faded, according to the Pennsylvania Department of Environmental Protection.

Human Health, Environmental, and Socioeconomic Risks of HABs and Hypoxia

HAB and hypoxia events are associated with a range of human health, environmental, and socioeconomic risks, according to reports from the working group and information from working group agencies.

Human Health Risks

Humans can experience a wide range of symptoms after exposure to marine and freshwater HABs, according to CDC's website, although the long-term health effects of HABs remain unclear.[13] Symptoms depend on the type of toxin, as well as the manner and duration of exposure. For example, neurotoxic shellfish poisoning resulting from eating shellfish contaminated with the marine HAB toxin brevetoxin results in short-term symptoms that include nausea, vomiting, and diarrhea.

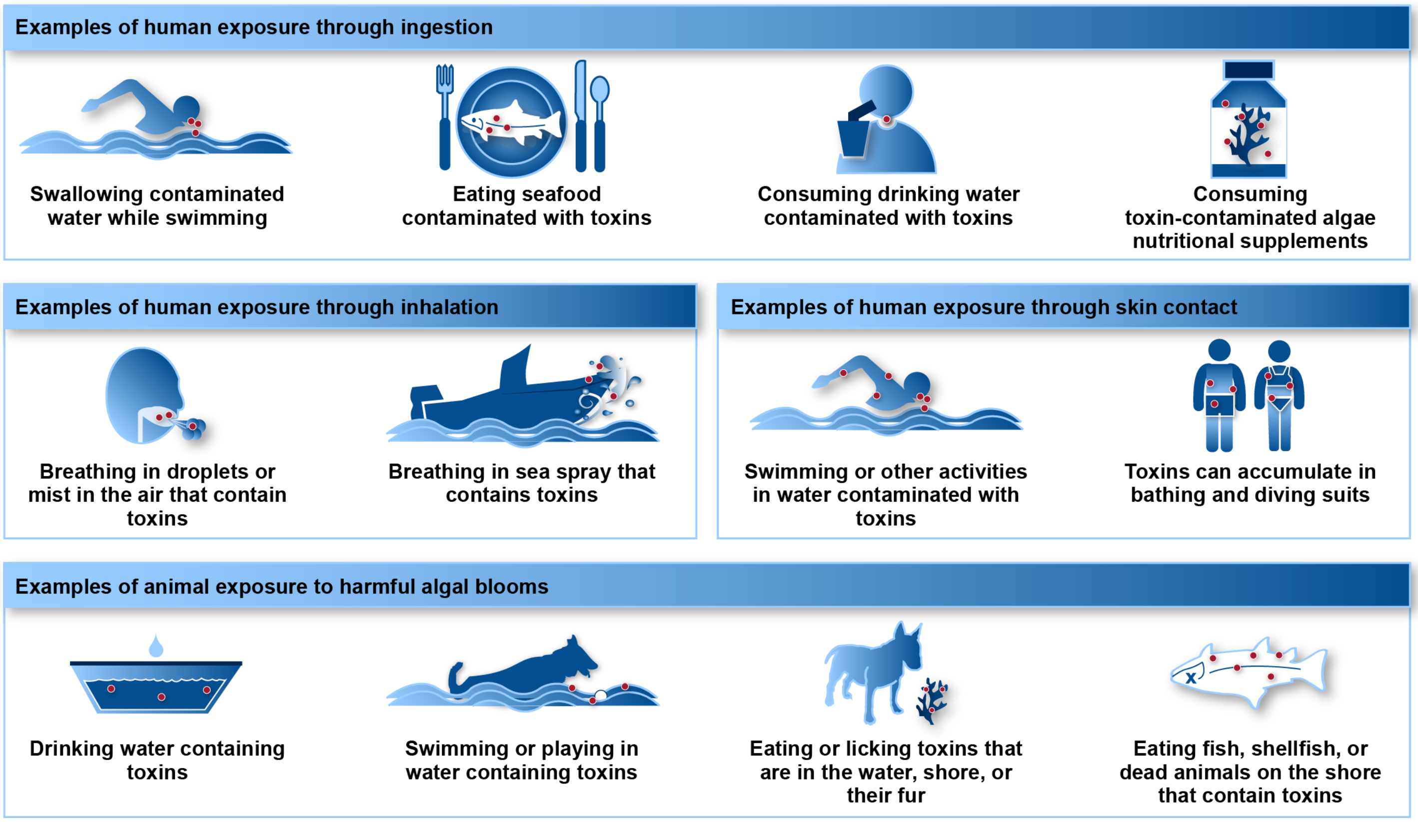
From 2016 through 2018, 94 percent of the reported human illnesses from HABs were linked to freshwater HAB events, according to a CDC report.[14] The CDC report found that exposures to freshwaters with an ongoing HAB may result in gastrointestinal, skin-related, and other symptoms. People (as well as pets, livestock, and wildlife) can be exposed to HAB toxins through various pathways, such as swimming in contaminated water or eating contaminated seafood, as shown in figure 2. However, humans do not experience health effects from hypoxia in water bodies.

[13]Centers for Disease Control and Prevention, "Illness and Symptoms: Marine (Saltwater) Algal Blooms" (Apr. 19, 2021), accessed June 16, 2021, https://www.cdc.gov/habs/illness-symptoms-marine.html; and "Illness and Symptoms: Cyanobacteria in Fresh Water" (Aug. 2, 2021), accessed Dec. 17, 2021, https://www.cdc.gov/habs/illness-symptoms-freshwater.html.

[14]The CDC report is based on data from 18 states that voluntarily reported 421 HAB events from 2016 through 2018, including information about 389 cases of human illness and 413 cases of animal illness associated with the HAB events. For more information, see Virginia A. Roberts et al., "Surveillance for Harmful Algal Bloom Events and Associated Human and Animal Illnesses—One Health Harmful Algal Bloom System, United States, 2016–2018," *Morbidity and Mortality Weekly Report*, vol. 69, no. 50 (Centers for Disease Control and Prevention, 2020).

Figure 2: Examples of Harmful Algal Bloom (HAB) Toxin Exposure Pathways for Humans and Animals

Exposure pathways may differ, depending on whether the toxin is from a marine or freshwater HAB.



Source: GAO analysis of information from the Centers for Disease Control and Prevention and Environmental Protection Agency. | GAO-22-104449

Environmental Risks

Animals can be poisoned by swimming in or drinking water containing HAB toxins, according to CDC's website.[15] For example, cattle are at risk because their movements are often confined by fencing and they may be forced to drink from ponds that contain HABs. In addition, marine algal

[15]Centers for Disease Control and Prevention, "Illness and Symptoms: Marine (Saltwater) Algal Blooms" (Apr. 19, 2021), accessed June 16, 2021, https://www.cdc.gov/habs/illness-symptoms-marine.html; and "Illness and Symptoms: Cyanobacteria in Fresh Water" (Aug. 2, 2021), accessed Dec. 17, 2021, https://www.cdc.gov/habs/illness-symptoms-freshwater.html.

Harmful Algal Bloom (HAB) Event: West Coast, 2015-2016

In the spring and summer of 2015, a marine HAB stretched from central California to the Alaska Peninsula. This led to multiple fishery and aquaculture closures and health advisories during the 2015-2016 fishing season, including California's commercial and recreational Dungeness crab and rock crab, and recreational razor clam fisheries. These closures resulted in extensive impacts and economic hardships on the commercial fishing and seafood industry, prompting the governor to request a fishery resource disaster and commercial fishery failure declaration.

Source: GAO analysis of California Ocean Science Trust information. Photo: National Oceanic and Atmospheric Administration. | GAO-22-104449

toxins may be consumed by small fish and shellfish and move up the food chain to affect larger animals, such as mammals, fish, and birds. For example, pelicans and cormorants have been poisoned by these toxins and, in some cases, thousands of birds have died, according to CDC's website.[16]

Even when HABs are not toxic, they can still cause harm to marine and freshwater ecosystems. For example, nontoxic HABs can lead to a range of unwanted effects, including unpleasant tastes and odors and harm to fish. In addition, high biomass blooms, whether of toxic or nontoxic species, can accumulate and decompose, causing excessive oxygen consumption that can lead to hypoxia. These conditions can then cause increased mortality rates in impacted fish, shellfish, invertebrate, and plant populations. Hypoxia can also affect animals that rely on fish for food, as they might have to leave an area to find the necessary food to survive.[17]

Although some hypoxia events can result from the decomposition of HABs, other hypoxia events are not related to HABs. Moreover, hypoxia also occurs naturally in many aquatic environments, such as in deep basins in the ocean, according to EPA's website.[18] Overall, the incidence of hypoxia has increased by almost thirtyfold in the U.S. since 1960, according to a 2016 report by the working group.[19] Our discussion of hypoxia in this report primarily focuses on HAB-related hypoxia events. However, information on federal actions that address hypoxia more generally is presented in appendix II.

[16]Centers for Disease Control and Prevention, "Illness and Symptoms: Marine (Saltwater) Algal Blooms" (Apr. 19, 2021), accessed June 16, 2021, https://www.cdc.gov/habs/illness-symptoms-marine.html.

[17]Environmental Protection Agency, "Hypoxia 101" (Nov. 16, 2021), accessed Nov. 18, 2021, https://www.epa.gov/ms-htf/hypoxia-101.

[18]Environmental Protection Agency, "Hypoxia 101" (Nov. 16, 2021), accessed Nov. 18, 2021, https://www.epa.gov/ms-htf/hypoxia-101.

[19]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report*.

Socioeconomic Risks

Harmful Algal Bloom Event: Salem, Oregon, 2018

In May 2018, the city of Salem, Oregon, issued a drinking water advisory for vulnerable populations, following the detection of algal toxins in Detroit Lake, which supplied drinking water to approximately 200,000 people.

The advisory lasted 33 days and impacted several industries and services. For example, hospitals, health care, and dialysis facilities were advised to not use water for patient care and to delay elective surgeries. Restaurants were advised to post notices to inform customers, and some food processors and breweries suspended production.

The governor declared an emergency and directed the Oregon Military Department to deploy portable water stations to the Salem area.

Sources: GAO analysis of information from the Oregon Department of Environmental Quality, Oregon Office of the Governor, and Environmental Protection Agency. Photo: U.S. Army Corps of Engineers. | GAO-22-104449

In addition to posing health and environmental risks, HABs and hypoxia can present social and economic risks to people and communities. Studies have shown that HABs and hypoxia can lead to losses in tourism, property values, and business revenues, according to reports by the working group.[20] For example, the tourism industry experiences losses in fishing and boating activities each year because of water bodies that have been affected by nutrient pollution and HABs, according to EPA's website.[21] Moreover, HABs can affect the tourism and recreation industries by causing beach closures and prompting health advisories, which, in turn, can lead to reduced profits for local businesses and social impacts on communities.

HABs and hypoxia can lead to adverse effects on aquatic species that result in losses of commercial and subsistence fish harvests, as well as limitations on recreational fishing, according to NOAA. As a result, HABs can socially and culturally disrupt communities that rely on marine and freshwater resources as a livelihood, including tribal and indigenous communities for which subsistence fishing is a primary food source.

HABs can pose risks to drinking water sources, resulting in increased costs. According to EPA, HABs in source waters can increase drinking water treatment, management, and operational costs. Adverse economic effects of HABs can also include public costs of health care to treat human illnesses caused by exposure, especially shellfish poisoning and respiratory and neurological ailments, according to NOAA. These effects can be impactful to individuals, families, and communities. For additional information about the socioeconomic impacts of HABs, see appendix III.

Factors Contributing to HABs and Hypoxia

While natural processes may cause some HABs and hypoxia, they cannot completely account for the observed marked increase in the number and duration of HAB and hypoxia events, according to a working group report.[22] According to the report, a combination of environmental and human activity factors can contribute to the formation of or increase

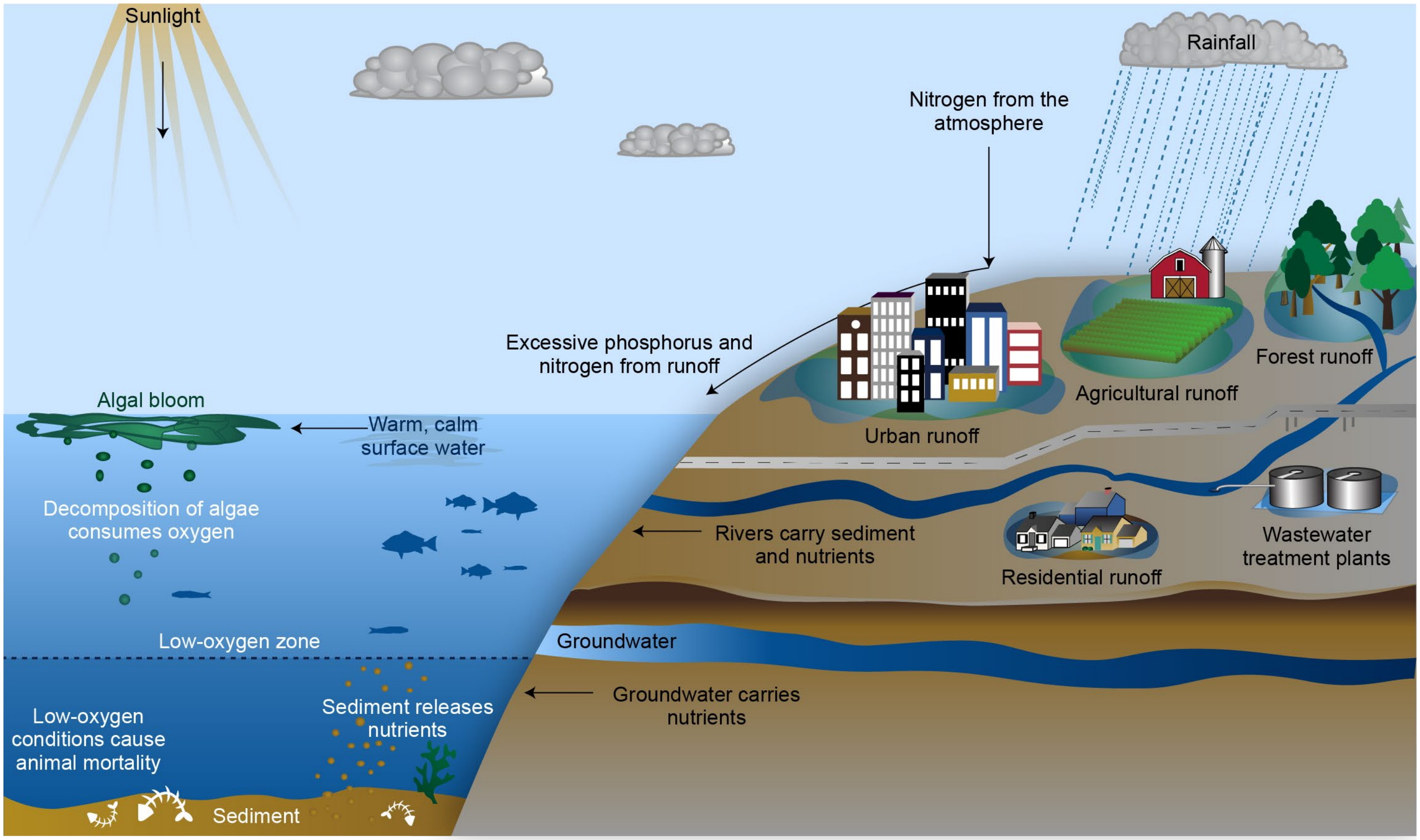
[20]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*; and *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report*.

[21]Environmental Protection Agency, "The Effects: Economy" (Mar. 1, 2021), accessed Jan. 26, 2022, https://www.epa.gov/nutrientpollution/effects-economy.

[22]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report*.

in HABs and hypoxia, some of which are shown in figure 3. For example, the impacts of climate change may promote the growth and dominance of HABs through warmer water temperatures, changes in salinity, increases in atmospheric carbon dioxide concentrations, changes in rainfall patterns, intensification of coastal upwelling, sea level rise, and other factors, according to EPA and NOAA. However, the factors that contribute to the production of toxins that cause some algal blooms to become toxic are not well understood, according to USGS officials.

Figure 3: Some Factors That Contribute to Harmful Algal Blooms and Hypoxia



Source: GAO analysis of information from the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act and the Lake Champlain Basin Program. | GAO-22-104449

Note: In some circumstances, such as in shallow water bodies and when turnover events bring deeper water to the surface, the low-oxygen zone may extend to the surface. In addition, some algae grow attached to the sediment and can form algal mats, which can be toxic.

Federal, State, Local, and Tribal Government Approaches to Identifying and Responding to HAB and Hypoxia Events

Numerous entities across federal, state, local, and tribal governments are involved in managing the risks of HAB and hypoxia events, including identifying and responding to these events. Federal agencies provide tools to identify when HABs and hypoxia are occurring by monitoring with satellites, ships, and other resources, and in some cases forecasting events using research and computer models. In addition, numerous federal agencies provide resources and expertise to support state, local, and tribal governments in responding to HAB and hypoxia events, according to NOAA and EPA officials. State, local, and tribal governments are generally the first to respond to HAB and hypoxia events, and they may seek federal assistance with larger events. Multiple state, local, and tribal entities can be involved, such as public health departments, departments of environmental protection and natural resources, pollution control agencies, and water utilities. Specific approaches in responding to HAB and hypoxia events vary by entity, region, or community, but the approaches generally involve mitigation, control, and prevention.

- **Mitigation** refers to responding to an existing or ongoing bloom by taking steps to restrict, inhibit, or prevent associated undesirable impacts on the environment, the economy, human health, and communities. For example, local officials may try to mitigate the impacts of HABs by restricting access to affected water bodies or issuing advisories to protect public health.
- **Control** refers to actions that directly kill HAB cells or destroy their toxins, physically remove cells and toxins from the water column, or limit cell growth and proliferation. Chemical, biological, physical, and environmental controls can be used to regulate or suppress HABs and hypoxia. Control activities can be controversial, however, due to concerns regarding potential unintended impacts of these controls on ecosystems. For example, while copper sulfate may kill HAB cells, it may also release toxins from those cells, and the resulting decaying plant matter may cause hypoxia, according to EPA officials.
- **Prevention** refers to environmental management actions taken to reduce the incidence and extent of HAB and hypoxia events. Prevention actions include minimizing nutrients flowing into coastal and inland waters (e.g., through the use of wetlands; green infrastructure; or conservation practices, such as riparian buffers); using aeration systems and flushing dams to prevent hypoxia; and using environmental controls (manipulation of an ecosystem environment, such as altering ecosystem habitat to disfavor growth of undesirable species).

Harmful Algal Bloom Event: Red Tide in Florida, 2017-2019

Beginning in November 2017, Florida experienced a 16-month red tide, which directly impacted 22 counties and harmed the state's economy, wildlife, water quality, natural resources, and public health. Tourism, aquaculture, fisheries, and many coastal businesses suffered. To protect the public from consuming shellfish affected by toxins from the red tide, state-managed aquaculture leases were closed for harvest in areas off southwest Florida from November 2017 until 5 months after the bloom had dissipated, an example of long-term economic impacts that persist after blooms subside. In addition, people were exposed to toxin-filled sea spray, with numerous reports of respiratory irritation and uncertain long-term effects. Fish kills of more than 100 species, including goliath groupers (pictured above), large-scale mortalities of sea turtles and manatees, and an unusual mortality event for bottlenose dolphins also occurred.

Source: GAO analysis of information from the Florida Fish and Wildlife Conservation Commission Harmful Algal Bloom Task Force. Photo: Florida Fish and Wildlife Conservation Commission. | GAO-22-104449

The Working Group Has Not Implemented a National HAB and Hypoxia Program or Developed Performance Measures to Assess the Results of Federal Efforts

The working group has taken some actions to help guide federal agencies' efforts to manage the risks of HABs and hypoxia, such as developing a research plan and action strategy, as required by the act, and developing other reports and planning documents. However, NOAA and EPA, as co-chairs of the working group, have not implemented a national HAB and hypoxia program under the act nor developed performance measures to assess the results of federal agencies' efforts to manage the risks of HABs and hypoxia.

The Working Group Has Not Implemented a National HAB and Hypoxia Program

We found that the working group has taken some actions to fulfill its responsibilities called for by the act, such as developing required plans and reports, but the group has not yet implemented a national HAB and hypoxia program under the act. The act calls for NOAA and EPA, acting through the working group, to maintain and enhance a national HAB and hypoxia program, which is to include a statement of objectives, including to understand, detect, predict, control, mitigate, and respond to marine and freshwater HAB and hypoxia events. As part of this program, the act called for the development of a comprehensive research plan and action strategy to address marine and freshwater HABs and hypoxia.

The working group developed the national HAB and Hypoxia Comprehensive Research Plan and Action Strategy in February 2016.[23] This document outlined federal agencies' roles and responsibilities for evaluating and managing HABs and hypoxia across the country, challenges to addressing HABs and hypoxia, and recommendations for federal research and actions to address HABs and hypoxia. Specifically, the working group recommended five goals for federal research and actions, including improving scientific understanding of HABs and hypoxia and strengthening new and existing monitoring programs. Table 1 provides an overview of these recommended goals and examples of related recommended actions.

[23]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report*.

Table 1: Recommended Goals and Examples of Related Recommended Actions in the Working Group's 2016 Research Plan and Action Strategy on Harmful Algal Blooms (HAB) and Hypoxia

Recommended goals	Description	Examples of recommended actions
Improve scientific understanding.	Additional and improved scientific understanding of HABs and hypoxia is needed, including on their causes and effects. In addition, there is a need for improved testing and research methods.	• Develop certified reference materials and other standardized and validated detection and analysis methods for HAB toxins.[a] • Understand the influence of climate change, atmospheric deposition of nutrients, and other contributing factors on the occurrence, frequency, and severity of HABs and hypoxia.
Strengthen and integrate new and existing monitoring programs.	A thorough and scientifically based monitoring program is critical to determining the location and extent of HAB and hypoxia occurrences so that their causes can be controlled.	• Strengthen long-term HAB and hypoxia monitoring activities. • Develop a rapid-response strategy for assessing HAB exposure.
Improve predictive capabilities.	Predictive models are critical for understanding HAB and hypoxia effects on ecosystems and for addressing the prediction of, and response to, toxins in drinking and recreational waters.	• Develop, improve, and validate HAB and hypoxia models and remote sensing.
Improve stakeholder communications, and develop a better understanding of socioeconomic and health-related impacts.	There is a need for improved communication among wildlife, veterinary, medical, and public health officials, as well as with the general public. In addition, more should be understood and shared among these groups about the socioeconomic and health-related impacts of HABs and hypoxia on local, regional, and national areas.	• Evaluate the socioeconomic impacts of HABs and hypoxia and the cost-effectiveness of mitigation, control, and prevention actions. • Identify susceptible populations at higher risk for HAB-associated adverse health effects.
Continue and expand collaborations in research, management, and policies.	Many of the research initiatives related to HABs and hypoxia have been made possible by collaborations between federal agencies, as well as between these agencies and state and local entities, the public, and academia. Further, additional collaboration can increase knowledge of these events to establish measures to mitigate the effects of HABs and hypoxia.	• Continue expanding relevant research, management, and policy collaborations. • Develop guidelines and tests, including real-time monitoring systems, for HAB toxins in drinking and recreational water.

Source: GAO analysis of information from the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act. | GAO-22-104449.

[a]According to the strategy, certified reference materials are analysis frameworks for identifying types of toxins and their concentrations. Certified reference materials also establish standards for the types and calibrations of instruments that are used to perform these analyses.

In March 2018, the working group released a report on the progress and implementation of the 2016 document. Among other things, the 2018 report identified actions the federal agencies in the working group planned to take nationwide through 2020 to address the recommendations from the 2016 document.[24] The working group has also developed a separate regional plan for reducing, mitigating, and controlling HABs and hypoxia in the Great Lakes, as called for in the act, as well as a subsequent report on the progress and implementation of this regional plan.[25] In addition, in September 2021, the working group developed a "Planning Document for Coordination." This document further specified the roles and responsibilities of the federal agencies in the working group, described working group efforts to engage with external stakeholders, and identified the recent, planned, and future activities of the working group and its member agencies through 2025. Taken together, the documents and reports demonstrate how federal agencies work to manage HAB and hypoxia risks.

The working group has not, however, implemented a national HAB and hypoxia program under the act, according to the NOAA and EPA co-chairs. The co-chairs told us that they have had conversations about the potential staffing and resources that would be required to run a national HAB and hypoxia program, but the working group has not formally defined what such a program would look like or identified a preferred approach.

According to the NOAA and EPA co-chairs, the working group has not implemented a national HAB and hypoxia program because of resource constraints and because the group has focused on other responsibilities, such as developing statutorily mandated reports. The act calls for the working group to, among other things, support the development of institutional mechanisms and financial instruments to further the objectives and activities of a national HAB and hypoxia program.[26] However, the officials raised the concern that neither NOAA nor EPA has received funding specific to implementing such a program, and they stated that the agencies would need resources for additional staff to

[24]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*.

[25]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report* (Washington, D.C.: Aug. 24, 2017); and *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report* (November 2020).

[26]33 U.S.C. § 4002(c)(4).

expand upon the existing coordination role of the working group.[27] According to the officials, neither NOAA nor EPA, as co-chairs of the working group, has the resources or staff needed to implement a national program to address marine and freshwater HABs and hypoxia.

NOAA officials said that the agency has received funding for its HAB research programs and for pilot projects related to monitoring and forecasting, but it has not received funding specifically for the operations of the working group, including managing a national HAB and hypoxia program. EPA officials said that the agency uses funding appropriated for broader water programs or research to address certain aspects of HABs and hypoxia, but that it has not received funding specifically for the implementation of a national HAB and hypoxia program. Moreover, NOAA officials explained that the working group itself is not a funding entity, and they said that developing a mechanism for coordinated funding among the federal agencies would enhance their ability to work together.

According to the Project Management Institute's *The Standard for Program Management*, a program is defined as related projects, subsidiary programs, and program activities managed in a coordinated manner to obtain benefits not available from managing them individually.[28] We have previously reported that *The Standard for Program Management* provides generally recognized leading practices for program management.[29]

The Standard for Program Management also provides an overview of a program's three life cycle phases and associated actions with each phase. The primary purpose of the first phase—program definition—is to progressively elaborate the goals and objectives to be addressed by the program, define the expected program outcomes and benefits, and seek

[27]According to NOAA officials, the working group has helped to enhance awareness, participation, and coordination for some agency-specific and interagency funding opportunities related to HABs and hypoxia, such as NOAA's competitive research program under the National Centers for Coastal Ocean Science.

[28]Project Management Institute, Inc., *The Standard for Program Management*, Fourth Edition, 2017. The Project Management Institute is a not-for-profit association that provides standards for managing various aspects of projects, programs, and portfolios.

[29]GAO, *Columbia River Basin: Additional Federal Actions Would Benefit Restoration Efforts*, GAO-18-561 (Washington, D.C.: Aug. 24, 2018). Program management intends to ensure that a program is continually aligned with an organization's strategic priorities to deliver the expected benefits, according to *The Standard for Program Management*. Aspects of program management include developing plans to engage stakeholders, communicating internally and externally, managing resources, and managing risks.

approval for the program. This phase begins with program formulation, which involves developing the business case for the program, including initiating studies and estimates of scope, resources, and cost.

Consistent with the practices established in *The Standard for Program Management*, an important next step to move forward with implementing a national HAB and hypoxia program will be to define what such a program would entail, including identifying the resources needed to implement the program. Doing so could help to inform agency and congressional decision-making regarding federal efforts to address HABs and hypoxia. By documenting and defining what a national HAB and hypoxia program would entail, including identifying the program's resource needs, NOAA and EPA, as the co-chairs of the working group, would be better positioned to implement the program and enhance federal efforts to manage the risks of HABs and hypoxia.

The Working Group Has Not Developed Performance Measures to Assess Results

The working group has not developed performance measures that would allow it to assess the results of federal efforts to manage the risks of HABs and hypoxia, including assessing progress toward achieving the recommended goals from the 2016 Research Plan and Action Strategy. We have previously found that performance measures provide managers with information on which to base their decisions and create powerful incentives to influence organizational and individual behavior.[30] However, the working group's published reports have focused on compiling lists of activities that its member agencies plan to take to address HABs and hypoxia. For example, the working group's March 2018 progress report presented a list of actions that federal agencies planned to take to address the recommendations from the 2016 document, including milestones such as expected completion dates, but it does not include performance measures.

Similarly, the September 2021 Planning Document for Coordination identifies actions the working group and its member agencies plan to take. The document includes expected completion dates for some actions, but it does not include performance measures to gauge the outcome of these efforts.

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[30] GAO, *Environmental Justice: EPA Needs to Take Additional Actions to Help Ensure Effective Implementation,* GAO-12-77 (Washington, D.C.: Oct. 6, 2011); and *Environmental Justice: Federal Efforts Need Better Planning, Coordination, and Methods to Assess Progress*, GAO-19-543 (Washington, D.C.: Sept. 16, 2019).

According to the Office of Management and Budget's Circular A-11, performance measurement is a means of evaluating efficiency, effectiveness, and results.[31] Likewise, we have previously reported that performance measures are important for tracking progress in achieving goals and are a key element of effective strategic planning.[32] Identifying planned actions and milestones, as the working group has done, can help to track the implementation of agency actions. However, on their own, the lists of planned actions and milestones do not serve as a way to assess the outcomes of federal efforts to manage the risks of HABs and hypoxia and the extent to which federal agencies have achieved the recommended goals from the 2016 Research Plan and Action Strategy. We have previously reported that milestones can help agencies track actions they have committed to implementing but that such milestones are not considered performance measures.[33]

Our previous work on interagency collaborative efforts, such as interagency working groups, has found that developing mechanisms to monitor, evaluate, and report on results is an important factor in the success of such efforts.[34] Officials from EPA and NOAA told us in October 2021 that the working group has not established performance measures because the group cannot formally direct agencies to take specific actions. However, in 2014 we reported that individual agency members participating in interagency collaborative efforts can choose to align their goals and actions with the interagency goals.[35] For example, we found that of the four interagency groups we had reviewed, all had developed performance measures—or other approaches to track contributions—within their own agencies that related to the outcomes of the interagency group.

Our prior work has found that failing to use performance measures and performance information to track progress toward outcomes can increase

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[31]Office of Management and Budget, Circular No. A-11, *Preparation, Submission, and Execution of the Budget* (Washington, D.C.: August 2021).

[32]See, for example, GAO-12-77 and GAO-19-543.

[33]GAO-19-543.

[34]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

[35]GAO, *Managing for Results: Implementation Approaches Used to Enhance Collaboration in Interagency Groups*, GAO-14-220 (Washington, D.C.: Feb. 14, 2014).

the risks of interagency efforts not achieving their outcomes.[36] Without developing performance measures, NOAA and EPA, as the co-chairs of the working group, cannot assess the results of federal agencies' efforts to manage the risks of HABs and hypoxia, including the extent to which the recommended goals from the 2016 Research Plan and Action Strategy have been achieved.

Federal Agencies Have Taken Limited Actions to Monitor and Forecast Freshwater HAB and Hypoxia Events

The extent of federal agency actions to monitor and forecast HABs and hypoxia varies by location and by type of water body. Federal agencies in the working group have taken actions to monitor HAB and hypoxia events in some coastal regions of the U.S., both in marine waters and in the Great Lakes, and have developed a framework to expand such monitoring through a proposed national network. However, even though freshwater HABs pose significant risks to human health, federal agencies have taken limited actions to monitor inland freshwater HAB and hypoxia events, and we found no organized, comprehensive effort to expand such monitoring for these water bodies. Federal agencies have also developed HAB and hypoxia forecasts for some coastal regions but have taken limited actions to develop forecasts for inland freshwater events.

Federal Agencies Monitor HAB and Hypoxia Events in Some Coastal Regions, but Monitoring of Freshwater Events Is Limited

Numerous federal agencies participate in efforts to identify when HAB and hypoxia events are occurring by monitoring with satellites and other tools.[37] NOAA is the lead federal agency for HAB and hypoxia events occurring in marine waters; EPA is the lead for events occurring in inland freshwater bodies; and EPA and NOAA work together for events in the Great Lakes, according to working group documentation.[38]

Monitoring in Marine Waters and the Great Lakes

Federal agencies use satellites and other tools to monitor HAB and hypoxia events in some marine waters and areas of the Great Lakes. For example, NASA provides satellite imagery of blooms and has funded basic and applied research, as well as technology development, to observe, understand, and predict the dynamics of HABs, according to

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[36] GAO-14-220.

[37] For the purposes of this report, we use the term "monitoring" to include efforts to observe, detect, or quantify HABs or hypoxia.

[38] The Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Planning Document for Coordination* (Sept. 29, 2021).

working group documentation.[39] In addition, NOAA has developed the HAB Monitoring System, which delivers near real-time satellite imagery for use in locating, monitoring, and quantifying algal blooms in some locations.[40]

NOAA and its partners, such as state agencies and tribes, also use other tools to determine whether a HAB is occurring in marine waters and in the Great Lakes. Monitoring tools can range from fully automated instruments to manually counting HAB cells in water samples collected from a beach or pier.[41] Many state monitoring programs determine whether a HAB is occurring by collecting samples in the field and bringing them back to the laboratory for analysis, according to NOAA.

In a 2020 report, NOAA identified some examples of automated and manual monitoring tools that can be used to determine whether a HAB is occurring, as shown in figure 4.[42] NOAA monitors hypoxia in some waters using ship surveys, autonomous underwater vehicles, and moored equipment (see app. II for information on actions that federal agencies have taken to monitor, forecast, and prevent hypoxia).

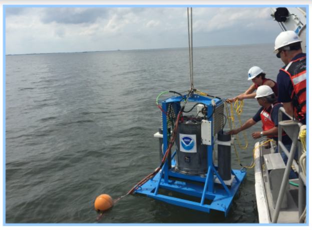
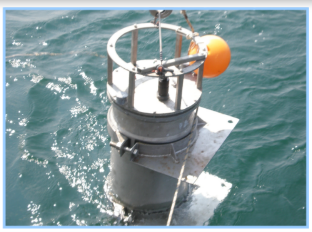
[39]The Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Planning Document for Coordination*.

[40]While species that cause HABs cannot be distinguished by satellites, satellites can detect high biomass blooms and separate bloom types by measuring proxies that estimate chlorophyll-a, the main component of the blooms. NOAA provides satellite imagery for Green Bay, Wisconsin; Saginaw Bay, Michigan; western Lake Erie; Chesapeake Bay; Albemarle Sound, North Carolina; Lake Pontchartrain, Louisiana; Lake Okeechobee, Florida; and coastal waters off of southwest Florida. For more information on NOAA's HAB Monitoring System, see https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/.

[41]In addition to monitoring using different tools, NOAA and academic partners collect records of HAB events in a central database. According to NOAA officials, the agency funds the U.S. National Office for Harmful Algal Blooms to collect reports of coastal and marine HAB events in U.S. waters through the Harmful Algae Event Database. The U.S. National Office for Harmful Algal Blooms, located at Woods Hole Oceanographic Institution, is funded by NOAA's National Centers for Coastal Ocean Science and supports the agency's HABs research. Specifically, the agency established the U.S. National Office for Harmful Algal Blooms to provide critical coordination and technical support capabilities that enhance the nation's ability to respond to and manage the growing threat posed by HABs. The office also acts as a liaison with the scientific community and related programs nationally and internationally. To access the Harmful Algae Event Database, see http://haedat.iode.org/.

[42]National Centers for Coastal Ocean Science and U.S. Integrated Ocean Observing System (National Oceanic and Atmospheric Administration), *Framework for the National Harmful Algal Bloom Observing Network: A Workshop Report* (Dec. 18, 2020).

Figure 4: Examples of Harmful Algal Bloom (HAB) Monitoring Tools Used to Assess HAB Events

HAB monitoring tool	Description	Example
Environmental sample processor		
	Also referred to as a "lab-in-a-can," this tool is an autonomous, robotic instrument capable of remotely determining in-water concentrations of HAB cells or toxins. Deployable on a mooring beneath the surface or on a pier, the tool filters particles from a water sample, extracts the target genetic material or toxin from any captured HAB cells, conducts a molecular analysis, and transmits the results to the operator in near-real time. The tool's measurements of cell or toxin concentrations provide resource managers with early warnings of HAB events and are used to inform and validate HAB forecast products for that location.	This tool has been deployed numerous times in marine (coasts of Washington and California, Gulf of Maine) and freshwater (Lake Erie) systems.
Imaging FlowCytobot		
	Also known as a "microscope-in-a-can," this tool takes pictures of, identifies, and counts HAB cells using image analysis software. This tool can be configured to transmit data in real time, even from remote locations. State public health managers and other users of the data can receive alerts when cell counts exceed a preestablished threshold. Imaging FlowCytobots can be deployed on piers, moorings, or autonomous vehicles; installed on ship flow-through seawater systems; or used in the lab.	In 2008, an Imaging FlowCytobot deployed on a pier in Texas detected a potential HAB associated with shellfish poisoning and helped to inform decisions to close oyster harvests and recall products to prevent many illnesses ahead of an "Oysterfest" event.
HABscope		
	The HABscope is a tool that allows for rapid, field-portable identification and enumeration of a specific species of algae, *Karenia brevis.* A water sample is placed in a chamber under a field-portable microscope. A cell phone with special software monitors the cells' characteristic swimming behavior and automatically counts the number of cells with that behavior and sends those data to a central, cloud-based repository.	Developed for use by volunteer networks, the HABscope needs volunteer coordinators and data managers to oversee the networks and ensure data quality. Data from the HABscopes are being used to inform an experimental respiratory forecast in Florida.
Standard microscopy		
	A person trained to identify HAB cells collects a water sample and examines it microscopically. Since a sample can contain hundreds of species, the person analyzing the material must have considerable expertise. Several days may elapse between collecting samples, transporting samples to a lab that may be far from the sampling site, preparing samples for analysis, and then identifying and counting the HAB organisms.	Many monitoring programs collect water or tissue samples in the field and bring them back to the laboratory for analyses. Microscopic cell counts are the standard approach for monitoring cell concentrations.

Source: GAO analysis of National Oceanic and Atmospheric Administration (NOAA) information; Photos: NOAA Great Lakes Environmental Research Laboratory; Woods Hole Oceanographic Institution, E. Taylor Crockford, August 2010; NOAA; motortion/stock.adobe.com. | GAO-22-104449

In 2020, NOAA found that a national HAB monitoring network is needed to integrate federal, regional, state, local, and tribal HAB observing capabilities in coastal regions.[43] In response to this need, NOAA developed a framework for a proposed National HAB Observing Network, which would enable it to expand monitoring in marine waters and the Great Lakes by integrating small-scale monitoring programs and regional HAB monitoring systems into a nationwide network. The framework includes an analysis of current monitoring capacities, future needs of each region, costs of different observing technologies, and next steps for implementation.[44] Implementing this framework may help NOAA and the working group make progress toward the recommended goal from the group's 2016 Research Plan and Action Strategy to strengthen HAB and hypoxia monitoring. NOAA estimates the cost for implementing the full monitoring network to be around $30 million. In fiscal year 2020, NOAA began implementing five pilot projects to demonstrate how this network might function.[45]

Monitoring in Inland Freshwaters

Multiple federal agencies engage in monitoring inland freshwater HAB and hypoxia events, but these efforts are limited in scope and do not cover many inland water bodies. For example, the Corps monitors the water bodies it manages for various parameters, including monitoring for HABs in some locations based on state policies, according to Corps officials.[46] In addition, EPA has taken actions to monitor HABs, such as requiring some public water systems to monitor cyanotoxins from 2018 to 2020 as part of the agency's Unregulated Contaminant Monitoring Rule program.[47] However, the scope of this effort was limited to treated

[43]National Centers for Coastal Ocean Science and U.S. Integrated Ocean Observing System (National Oceanic and Atmospheric Administration), *Framework for the National Harmful Algal Bloom Observing Network: A Workshop Report*.

[44]NOAA refers to the framework as a first step, to be followed by an implementation plan, governance strategy, identification of stakeholder support, integration with NOAA's annual budget process, and making information publicly available.

[45]Integrated Ocean Observing System Association, *Implementation Strategy for a National Harmful Algal Bloom Observing Network (NHABON)* (February 2021).

[46]Corps officials said that the agency is also involved in responding to HABs that occur in the water bodies it manages. In addition, the Corps is working to develop monitoring technologies, as described in appendix IV.

[47]EPA established its Unregulated Contaminant Monitoring Rule Program under the Safe Drinking Water Act to monitor drinking water for unregulated contaminants. That act requires EPA to issue a list every 5 years of not more than 30 contaminants to be monitored by public water systems. 42 U.S.C. § 300j-4(a)(2)(B). Unregulated drinking water contaminants are those that are not currently regulated by the National Primary Drinking Water Regulations under the Safe Drinking Water Act.

drinking water and, therefore, did not include monitoring of freshwater bodies.

EPA has collected data on the presence of HAB and hypoxia indicators in a selection of freshwater bodies across the nation as part of its National Aquatic Resource Surveys. While not providing comprehensive assessments of HAB events in individual waters, the survey results provide national and regional context for indicators of potential HAB events across water bodies and track changes over time. EPA officials said that the results from these surveys provide useful information to help prioritize additional monitoring in areas that are more likely to experience HABs. However, the purpose of the surveys is to periodically assess the condition of the nation's water bodies, and they are not designed to provide EPA with real-time data on the occurrence and impacts of HAB and hypoxia events.[48]

EPA has also collaborated with NASA, NOAA, and USGS to develop a tool that uses satellite imagery to help water quality managers detect algal blooms in certain U.S. freshwater bodies. This tool, known as the Cyanobacteria Assessment Network (CyAN) application, allows for monitoring in over 2,000 of the nation's largest lakes and reservoirs, as well as some larger rivers and estuaries.[49] However, since satellite

[48]The National Aquatic Resource Surveys use a statistically representative sample to report on the broad population of waters and rotate through lakes, rivers and streams, estuarine coastal waters, Great Lakes nearshore waters, and wetlands on a 5-year cycle. For example, EPA assesses lakes through these surveys every 5 years and, in doing so, collects data on one type of algal toxin. However, publication of the survey results may take several years from the date of data collection, hampering timely access to data to inform management decisions. For example, as of March 2022, the most recently available National Lakes Assessment was published in 2012. For more information, see https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys.

[49]The CyAN project officially started in 2015, and the CyAN application was released for public use in 2019. In addition to the lakes in the continental U.S., CyAN also added satellite imagery for 5,000 freshwater systems in the state of Alaska, according to EPA officials.

The Cyanobacteria Assessment Network (CyAN)

The CyAN app provides a customizable interface to scan water bodies for changes in cyanobacteria occurrence. Users of the CyAN app can view information about cyanobacteria concentrations on a national scale or can zoom in for data on a lake or reservoir. Lake managers, for example, can look at imagery on their computer or mobile device to identify cyanobacterial blooms and then focus their monitoring resources on those areas.

CyAN has supported the issuance of recreational advisories to help people avoid illness when deciding where to recreate in some states, according to Environmental Protection Agency (EPA) officials. For example, in 2020, the Wyoming Department of Environmental Quality used a combination of CyAN imagery and public reports to issue recreational use advisories for multiple lakes.

Sources: GAO analysis of information from EPA and the Wyoming Department of Environmental Quality. Photo: EPA. | GAO-22-104449

limitations restrict the use of CyAN to larger water bodies, this tool does not provide monitoring information for the large number of smaller lakes and water bodies across the country.[50] For additional examples of actions taken by EPA, the Corps, and other federal agencies to monitor freshwater HAB and hypoxia events, see appendix IV.

The working group and other stakeholders have recognized the need for a more comprehensive approach to monitor and collect data on freshwater HABs. For example, in a 2018 report, the working group identified the need for more complete national data on freshwater blooms.[51] Officials from 13 states in our discussion groups said federal agencies should play a role in advancing sustained, national monitoring and data collection of HABs to help them respond to and manage HAB events. Furthermore, the EPA Office of Inspector General (OIG) reported in September 2021 that EPA needs to establish a national HAB event monitoring and tracking system to better define the magnitude of the problem and assess the risks that freshwater HABs pose to human health and the environment.[52]

We have previously identified leading practices for enterprise risk management that can help federal agencies manage risks, such as those

[50]Satellites cannot directly detect cyanobacteria or their toxins, but they can provide estimated measures of cyanobacteria, according to EPA's website. While CyAN is useful to help guide ground-based monitoring, at this time water sampling is still required to better understand the spatial and temporal dynamics of cyanotoxin production, according to U.S. Fish and Wildlife Service officials.

[51]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*.

[52]Environmental Protection Agency, Office of Inspector General, *EPA Needs an Agencywide Strategic Action Plan to Address Harmful Algal Blooms*, 21-E-0264 (Washington, D.C.: Sept. 29, 2021).

posed by HABs and hypoxia.[53] These practices call for agencies to assess risks and monitor how those risks are changing to select the appropriate risk responses. In doing so, it is important to use the best information available to make risk assessments as realistic as possible.

However, we found there is no organized, comprehensive effort to expand monitoring of inland freshwater bodies for HABs and hypoxia. EPA officials said there is a need to conduct monitoring and to track the extent, duration, and frequency of the occurrence and effects of HAB and hypoxia events, but EPA has not assessed what it would take to monitor these events across the U.S. According to EPA officials, the agency has been limited in its efforts to monitor freshwater HABs and hypoxia because of the large number of inland freshwater bodies—EPA identified approximately 160,000 lakes in the U.S. in the 2012 National Lakes Assessment—and the complexity and costs of monitoring.[54] EPA officials said that the diverse nature of freshwater HABs and their toxins makes it challenging to monitor them and requires more individualized instrumentation, site-specific sampling designs, and a data management system, among other things. For these reasons, according to the officials, EPA would need additional resources, including staff and funding, to more comprehensively monitor freshwater HABs and hypoxia.

As the co-chair of the working group, EPA has the opportunity to leverage the expertise and tools of the other participating federal agencies to expand interagency monitoring of freshwater HABs and hypoxia. For example, the Corps has developed remote sensing tools that may be able to help expand monitoring for HABs in some smaller water bodies, according to agency officials. In addition, USGS is working to advance understanding of the factors involved in toxin production and release, with the goal of developing tools that can more effectively monitor and characterize toxic HABs. According to NOAA and EPA officials, the working group can play a role in the coordination of technology and

[53]GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risk*, GAO-17-63 (Washington, D.C.: Dec. 1, 2016). According to the Office of Management and Budget's Circular A-123, federal leaders and managers are responsible for implementing management practices that effectively identify, assess, respond, and report on risks.

[54]Environmental Protection Agency, *National Lakes Assessment 2012: A Collaborative Survey of Lakes in the United States*, EPA 841-R-16-113 (Washington, D.C.: December 2016). According to EPA officials, there are also more than 3.5 million miles of rivers and streams in the U.S.

knowledge transfers, and can play a role in collaboration to develop tools to help states monitor for HABs.

The working group could, therefore, serve as a coordination platform through which EPA could work with other federal agencies to develop an interagency framework for expanding freshwater HAB and hypoxia monitoring. The working group highlighted the need to strengthen monitoring efforts as one of the recommended goals in its 2016 Research Plan and Action Strategy, and developing an interagency framework to expand freshwater monitoring could help the group make progress toward achieving this goal. Such a framework could include identifying current freshwater HAB and hypoxia observing capabilities, developing an implementation plan, and identifying resource needs, similar to NOAA's framework for expanding monitoring of HABs in the Great Lakes and marine waters. Given the varying state, county, and local jurisdictions and the complex coordination needed to monitor the large number of inland freshwater bodies, such a framework could also help to prioritize among the water bodies. By developing an interagency framework for expanding freshwater HABs and hypoxia monitoring, including prioritizing water bodies and identifying resource needs, EPA and the working group would be better positioned to monitor freshwater HAB and hypoxia events and obtain the information needed to manage the risks from such events.

Federal Agencies Forecast HAB and Hypoxia Events in Some Coastal Regions, but Forecasting of Freshwater Events Is Limited

NOAA develops forecasts for marine HABs and hypoxia in some coastal regions and partners with EPA to develop forecasts for parts of the Great Lakes.[55] NOAA has also developed a framework to advance its ability to forecast regional marine and Great Lakes HAB and hypoxia events. However, EPA and other federal agencies have taken limited actions to develop forecasts for HAB and hypoxia events in inland freshwater bodies.

Forecasting in Marine Waters and the Great Lakes

Forecasts help to predict when HABs or hypoxia will occur ahead of the actual event, which can help to guide timely decision-making, such as when to issue beach and seafood harvest closures to reduce human health risks. NOAA officials said that the agency's forecasts depend in

[55]According to NOAA documents, NOAA's forecasts can be short term, long term, and scenario based. Short-term HAB forecasts predict the intensity, location, and trajectory of blooms, as well as the respiratory health risks of HABs in some areas several days in advance of their arrival. Long-term forecasts predict whether HAB events in the upcoming bloom season will be more or less severe. Scenario forecasts test the impact of changing environmental conditions, such as nutrient pollution and climate change, on bloom formation and expansion.

part on the information collected through monitoring efforts. According to NOAA officials, forecasts are complex and difficult to develop because they require baseline information on various algae and ocean dynamics to develop models capable of making accurate predictions.

NOAA produces operational forecasts for marine HABs and hypoxia in some coastal regions and partners with EPA, through the Great Lakes Restoration Initiative, to develop forecasts for parts of the Great Lakes.[56] For example, NOAA issues regular forecasts for red tide—a type of HAB—in the Gulf of Mexico, specifically in Florida and Texas, through which state and local coastal resource managers, public health officials, and research scientists receive information on the predicted size and trajectory of blooms.[57] NOAA also forecasts respiratory irritation from HABs at individual beach locations in Florida and posts this information online to help the public make informed choices about where and when to visit areas that may be temporarily affected by a bloom. According to state officials in Florida, NOAA's forecast has been a successful tool to protect public health.

NOAA has not developed HAB and hypoxia forecasts for all coastal regions but has taken steps to address this gap. For example, while there are no operational forecasts in Alaska, NOAA officials said that the agency is working with local partners to support the development of forecasts for southwest Alaska and other areas. NOAA has also identified operational HAB and hypoxia forecasting as a priority area in its ecological forecasting strategy.[58] In addition, NOAA's framework for developing a National HAB Observing Network is intended to help address this priority by implementing operational HAB monitoring required to support complex forecasts, as well as addressing other early warning

[56]According to NOAA officials, operational forecasts are those that NOAA supports directly and issues annually throughout a region's entire bloom season. NOAA also produces some forecasts that are primarily supported with research funding, as well as some demonstration and experimental forecasts. NOAA has developed HAB forecasts for California, the Gulf of Maine, the Gulf of Mexico, Lake Erie, Lake Huron, and the Pacific Northwest. NOAA has also developed hypoxia forecasts for Chesapeake Bay, the Gulf of Mexico, and Lake Erie. For more information on NOAA's ecological forecasts, see https://oceanservice.noaa.gov/ecoforecasting/.

[57]For more information on NOAA's Gulf of Mexico HAB forecasts, see https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-forecasts/gulf-of-mexico/.

[58]National Oceanic and Atmospheric Administration, *A Strategic Vision for NOAA's Ecological Forecasting Roadmap 2015-2019*.

needs of resource managers and public health officials, according to NOAA documentation.

Forecasting in Inland Freshwaters

While NOAA has developed a framework to advance its ability to monitor, and subsequently forecast, marine and Great Lakes HAB and hypoxia events, EPA has taken limited actions to forecast inland freshwater events. EPA, through the working group, is to participate in forecasting freshwater HABs in lakes, rivers, estuaries, and reservoirs as part of its directive under the act.[59]

According to EPA officials, EPA is conducting studies and developing models to advance its ability to forecast freshwater HABs and hypoxia. For example, EPA has used satellites and modeling to estimate the likelihood of cyanobacteria blooms in some Florida water bodies.[60] However, although EPA's research is an important step toward advancing forecasting of freshwater HABs, it is limited to certain freshwater bodies and is not currently used as an operational forecast that managers can refer to when making public health decisions.

Leading practices for enterprise risk management call for agencies to examine the likelihood of a risk's occurrence and the potential impact of the risk, such as through forecasting HAB and hypoxia events.[61] However, federal agencies in the working group have identified challenges to advancing freshwater forecasting. For example, in its 2018 report, the working group stated that more complete freshwater HAB datasets are needed to develop improved forecasting. Both EPA and NASA officials stated that federal forecasting capabilities are dependent on monitoring data, which are not comprehensive, as discussed above.

In September 2021, the EPA OIG reported that EPA has not taken a sufficient leadership role in mitigating freshwater HABs and recommended that it develop an agency-wide strategic action plan to

[59]*See* 33 U.S.C. § 4002(h)(1)(B).

[60]EPA officials told us that they are planning to test their Florida-based model more broadly across the nation in the future. For more information, see Mark H. Myer et al., "Spatio-Temporal Modeling for Forecasting High-Risk Freshwater Cyanobacterial Harmful Algal Blooms in Florida," *Frontiers in Environmental Science*, vol. 8 (Nov. 2, 2020).

[61]GAO-17-63.

address this, including in the area of forecasting.[62] Developing such a plan is an important step, but forecasting freshwater HABs and hypoxia is also an interagency effort. For example, according to NASA officials, NASA has tools to develop models to help understand the drivers of HABs, but federal agencies need to work together to identify the types of data needed to do this. In its 2021 planning document, the working group identified nine federal agencies as having roles and responsibilities related to HAB and hypoxia forecasting.[63]

As the co-chair of the working group and lead federal agency for freshwater HABs and hypoxia, EPA is responsible for leading the effort to forecast freshwater HABs and hypoxia. Through the working group, it also has the opportunity to leverage the expertise and tools of the other participating federal agencies to develop an interagency framework to expand forecasting of freshwater HABs and hypoxia. As with monitoring, such a framework could include prioritizing freshwater bodies for forecasting and identifying resource needs.

The working group highlighted the need to improve predictive capabilities as one of the recommended goals in its 2016 Research Plan and Action Strategy, and developing an interagency framework to expand freshwater forecasting could help the group make progress toward achieving this goal. By developing such a framework, including prioritizing water bodies and identifying resource needs, EPA and the working group would be better positioned to forecast when freshwater HAB and hypoxia events will occur and to manage the risks from such events.

62In its response to the OIG report, EPA stated that it expects to develop this plan by January 2023. For more information, see Environmental Protection Agency, Office of Inspector General, *EPA Needs an Agencywide Strategic Action Plan to Address Harmful Algal Blooms*.

63The Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Planning Document for Coordination*. The working group identified EPA, NOAA, and USGS as authorized to conduct forecasting activities, and the Bureau of Indian Affairs, the Corps, NASA, National Institute of Environmental Health Sciences, National Science Foundation, and NRCS as having a participatory or supportive role in forecasting.

Federal Agencies Help State, Local, and Tribal Governments Respond to HAB and Hypoxia Events but Lack a Prevention Goal and Have Limited Cost-Benefit Information

Federal agencies in the working group have taken a variety of actions to help state, local, and tribal governments respond to HAB and hypoxia events. The working group and state officials in our discussion groups identified the need for more actions to prevent HABs and hypoxia, but the working group has not developed a goal to help focus greater attention on prevention efforts. In addition, federal agencies in the working group have developed limited information to help state, local, and tribal governments compare the costs and benefits of different response options for HAB and hypoxia events.

Federal Agencies Have Helped State, Local, and Tribal Governments Respond to HAB and Hypoxia Events

State, local, and tribal governments are often at the forefront of responding to HAB and hypoxia events and may receive assistance from federal agencies in doing so, as discussed previously. In our discussion groups, state officials said that they respond to HAB events by using mitigation efforts, such as gathering information and communicating with the public about the risks associated with affected water or seafood. Officials from local governments told us that they have worked with state governments to take steps to control or prevent HABs and hypoxia, such as using systems that distribute oxygen in the water. However, states and selected localities and tribes we spoke to told us that they are challenged to maintain dedicated programs to manage and respond to HAB and hypoxia events. For additional information on the experiences of these localities and tribes, see appendix V.

Federal agencies can play an important role in helping states, localities, and tribes respond to HAB and hypoxia events. We found that federal agencies have generally accomplished this by taking four main types of actions: (1) providing written guidance, (2) providing technical assistance, (3) providing funding, and (4) conducting research.[64]

Written Guidance

To help state, local, and tribal governments respond to HAB events, several federal agencies provide written guidance on a number of topics, including information on safety levels for toxins, drinking water safety, and

[64]Although the federal government primarily provides guidance, technical assistance, and funding directly to states and tribes, local governments may generally access these through their state agencies.

communicating the risks of HABs. These agencies include EPA, CDC, and the Food and Drug Administration.

EPA has several efforts to provide guidance to state, local, and tribal governments. For example, EPA has provided written guidance on safety levels for two types of HAB toxins—cylindrospermopsins and microcystins. This guidance includes information on when state, local, and tribal governments should alert the public, such as by posting signs on recreational waters and issuing alerts about drinking water to warn the public about the danger of toxins. EPA's guidance for these two types of toxins provides numeric advisory thresholds for drinking and recreational waters to help states determine when actions should be taken to protect the public.[65] EPA's guidance on toxin levels can mitigate the impacts of HABs by allowing state, local, and tribal governments to share information with the public about the risks that specific HAB events pose to fishing and help people to avoid waters containing HABs (see fig. 5).

Figure 5: Examples of Harmful Algal Bloom (HAB) Advisories Posted by States

Sources: New Jersey Department of Environmental Protection (left) and Oregon Department of Agriculture (right). | GAO-22-104449

Note: The photo on the left is one of four alert categories used by the New Jersey Department of Environmental Protection, each providing recommendations of activities that should not be pursued based on HABs water monitoring results, according to a department official. The photo on the right is an example of a biotoxin closure sign in Oregon, which is used when biotoxins from HABs have accumulated to the point where a shellfish harvest area must be closed, according to an official from the Oregon Department of Agriculture.

[65] Thresholds for HAB toxins are set for levels of exposure over different periods, such as one day, 10 days, or a lifetime.

Officials from seven states participating in our discussion groups identified the need for EPA to issue advisory thresholds for additional HAB toxins, such as anatoxin-a and saxitoxin. EPA officials reported that the agency is developing new guidance on toxin thresholds and monitoring. EPA also provides other tools on its website, such as communication templates and examples, to help water managers inform people using recreational waters about the risks of HABs.[66]

EPA has also issued criteria for water quality standards to be adopted by states and tribes, which can help to support efforts to prevent HABs and hypoxia.[67] For example, in 2000 and 2001, EPA published ambient water quality criteria recommendations to address nutrient pollution (specifically nitrogen and phosphorus) in rivers and streams.[68]

Other federal agencies, including CDC and the Food and Drug Administration, also publish guidance that state, local, and tribal officials can use to mitigate the impact of HAB events. For example, CDC provides guidance to help health care providers and public health professionals identify human and animal health symptoms of exposure to HABs. Officials from two states in our discussion groups said they used these resources to inform veterinarians about the impacts of HABs on animals, such as pets. The Food and Drug Administration provides guidance about foodborne illnesses caused by some types of HABs.

Technical Assistance

Federal agencies provide technical assistance to help state, local, and tribal governments respond to HAB and hypoxia events, often in support

[66]In September 2021, the EPA OIG recommended that EPA assess and evaluate the available information on human health risks from exposure to certain HAB toxins in drinking water and recreational waters to determine whether actions under the Safe Drinking Water Act are warranted. EPA Office of Inspector General, *EPA Needs an Agencywide Strategic Action Plan to Address Harmful Algal Blooms*.

[67]EPA also administers a program, known as the Nutrient Scientific Technical Exchange Partnership and Support Program, which provides states, territories, and authorized tribes with direct technical support to develop numeric nutrient criteria, upon their request. According to EPA, the agency has provided direct technical support to 48 states to assist them in their efforts to develop numeric state-specific or site-specific nutrient criteria.

[68]"Ambient" refers to open waters, such as rivers, lakes, and streams, as opposed to closed water supply systems that distribute treated water or wastewater. As of November 2021, Hawaii was the only state to adopt the numeric criteria for both nitrogen and phosphorus into its statewide water quality standards for rivers and streams. An additional 12 states had adopted numeric criteria for both nutrients, but only for some rivers and streams, or had adopted the criteria for one nutrient only. The remaining 37 states had not adopted any aspects of the numeric criteria for either nutrient into their water quality standards.

of mitigation efforts to help the public avoid affected locations and seafood. Providing technical assistance is an important role that the federal government plays in mitigating the risks of HABs and hypoxia, according to officials from 34 of the 37 states represented in our discussion groups.

EPA provides several kinds of technical assistance to state, local, and tribal governments. For example, according to state and tribal officials, EPA regions have provided laboratory resources for states and tribes to test water for HAB toxins, such as access to specialized instruments and trained technicians. EPA, according to agency officials, has also provided technical assistance through regional workshops and trainings for state and tribal governments. Other federal agencies have also contributed to such efforts by participating in some of the events. EPA officials stated that through these workshops and trainings, they shared information on managing the risks of HAB events, including what federal resources are available for states and tribes. In addition, officials stated that EPA provides technical assistance to drinking water systems that experience cyanotoxins in their source waters. This includes technical support on treatment, monitoring, risk communication, and laboratory analysis.

Other federal agencies have also provided technical assistance related to HABs and hypoxia to state, local, and tribal governments. For example, one state official described working closely with the Corps to learn about testing protocols and for help identifying potential HABs. States also described working with the Food and Drug Administration on laboratory testing and analysis of shellfish and water samples through the National Shellfish Sanitation Program. In addition, NOAA provides technical assistance to help federal, state, local, and tribal officials manage HAB events through its HAB Event Response Program.

Funding

Federal agencies, including CDC, EPA, and NOAA, provide funding that states, localities, and tribes can use to hire staff or fund HAB monitoring programs. State officials cited the importance of federal funding for these purposes, and tribal officials said that federal funding supports their water quality programs, including HAB-related efforts. For example, tribal officials we interviewed said they use EPA funding to pay for staff and monitoring initiatives related to HABs.

Funding from federal agencies is also available for mitigation, control, and prevention activities. For example, CDC provides funding to states through cooperative agreements to support data collection related to HAB mitigation efforts. These funds support collecting data on the health effects of HABs and reporting the data to the One Health Harmful Algal Bloom System, a voluntary reporting system. These activities help state officials understand and track how many people and animals experience negative health effects associated with HAB events.[69]

EPA provides funding through various programs that can help state, local, and tribal governments respond to HAB and hypoxia events. For example, EPA provides grants to states, localities, and tribes through its Clean Water Act section 319 program to fund projects to reduce nonpoint sources of pollution and restore water bodies impaired by such pollution, which may help to prevent HABs.[70]

NOAA's HAB Event Response Program also provides immediate financial assistance to help federal, state, local, and tribal officials manage events and advance the understanding of HABs as they occur. For example, during a 2020 HAB and hypoxia event in California, funding from this program was used to analyze environmental and wildlife samples for toxins, as well as to investigate the causes of animal die-offs and the public health implications of the event.

In addition, NRCS provides funding for private landowners to conserve land and carry out conservation practices that reduce nutrient runoff and can benefit water quality, including by helping to prevent HABs and hypoxia. For example, through the Environmental Quality Incentives Program and other initiatives, NRCS provides financial assistance to agricultural producers to implement conservation practices that reduce nutrient runoff. Figure 6 presents an example of a NRCS-funded conservation practice, known as a bioreactor, to reduce nutrient pollution from a farm in Wisconsin.

[69]For more information on CDC's funding for HABs-related activities, see https://www.cdc.gov/habs/public-health-capacity.html.

[70]Nonpoint source pollution is pollution from diffuse sources, such as runoff from farms or construction sites. According to EPA, nonpoint source pollution is caused by rainfall and snowmelt moving over and through the ground, which picks up and carries away natural and human-made pollutants as it moves and eventually deposits them into lakes, rivers, wetlands, coastal waters, and ground waters.

Figure 6: Example of a Bioreactor Funded by NRCS to Reduce Nutrient Pollution

Bioreactor being built

Bioreactor being filled with wood chips

Bioreactor completed

Source: U.S. Department of Agriculture Natural Resources Conservation Service (NRCS). | GAO-22-104449

Note: A bioreactor is a conservation practice that uses wood chips to reduce nutrients (nitrates) in water draining from farmland. As water moves through the bioreactor, microorganisms in the wood chips convert the nitrates to nitrogen gas.

For additional information on NRCS's programs and other examples of federal agency efforts to provide funding to help states, localities, and tribes respond to HAB and hypoxia events, see appendix VI.

Research

Federal agencies also perform research that can help state, local, and tribal governments respond to HAB and hypoxia events. For example, according to officials, in 2019, the Corps' Engineer Research and Development Center established a Freshwater Harmful Algal Bloom Research and Development Program that focuses on the prevention, detection, and management of freshwater HABs. This program had more than 30 active research and development projects underway as of December 2021, according to Corps officials. In addition, as of December 2021, the Corps was finalizing the development of a plan for addressing its HAB-related research needs, which Corps officials said will include information on funding needs and time lines for research activities, as well as opportunities to partner with academia and other entities. The Corps also has other HABs-related research underway, such as an effort to develop technology—known as the Harmful Algal Bloom Interception, Treatment, and Transformation System—to remove HABs from water bodies and transform the material into biofuel, according to Corps officials.

NRCS and the Agricultural Research Service conduct research through the Conservation Effects Assessment Project to quantify the environmental effects of conservation practices and programs, including practices that may help to prevent HABs. According to NRCS officials, the Department of Agriculture uses the findings from this project to guide its conservation policy and program development and to help conservationists, farmers, and ranchers identify more effective conservation practices and make more informed conservation decisions.

NOAA also supports several research programs related to HABs through its National Centers for Coastal Ocean Science and Sea Grant program. These research programs include Ecology and Oceanography of HABs; Monitoring and Event Response for HABs; and Prevention, Control, and Mitigation of HABs. For example, the Ecology and Oceanography of HABs program funds research to understand the causes and impacts of HABs and their toxins. In addition, NOAA officials said that these programs support the development of HABs prevention, control, and mitigation strategies. For more information on these programs and additional examples of federal agency efforts to perform research that can help states, localities, and tribes respond to HAB and hypoxia events, see appendix VI.

Federal Agencies and State Officials Have Identified a Need for More Actions to Prevent HABs and Hypoxia

Federal agencies in the working group have taken some actions to help state, local, and tribal governments prevent HABs and hypoxia, as described above. However, the working group and state officials in our discussion groups identified the need for more prevention actions, particularly related to nutrient reduction.[71] In 2018, the working group reported that reducing nutrient pollution from urban and agricultural landscapes is key to addressing HABs and hypoxia across the country and that many locations will need further assistance from the government to do so.[72] State officials in our discussion groups also identified a need for federal prevention actions, including nutrient reduction projects, to help them respond to HAB events. Officials in four of our seven discussion groups identified nonpoint source pollution from agricultural fields and other sources as a challenge in managing HABs. One official stated that more funding is needed for prevention projects because nutrients are the biggest contributor to HABs.

[71]For the purposes of this report, “prevention” does not mean eliminating all occurrences of HAB and hypoxia events but rather reducing the number and severity of these events.

[72]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation*.

The working group plays a role in coordinating and advancing actions to prevent HABs and hypoxia, according to working group documentation. However, although the working group and others have identified the need for more prevention actions, the group did not include implementing prevention actions among the five goals for federal research and actions in its 2016 Research Plan and Action Strategy.[73] Instead, the goals focused on other elements of responding to HAB and hypoxia events, including strengthening monitoring and improving stakeholder communications.[74]

Our previous work on interagency collaborative efforts, such as interagency working groups, has found that establishing clear, shared goals is an important practice that can help such groups achieve desired outcomes and be accountable for results.[75] Some individual agencies in the working group, including EPA and NRCS, have supported prevention actions, such as by providing funding to state, local, and tribal entities to implement conservation practices to reduce nutrient pollution. However, according to NOAA officials, prevention actions tend to be more agency-specific and geographically-specific than mitigation actions, and the working group overall has generally focused more on mitigating the impacts of HABs and hypoxia than on prevention efforts. As a result, in the absence of a shared national goal to help focus greater attention on prevention efforts, the extent to which federal agencies in the working group will address the need for more prevention actions is unclear.

NRCS officials said that part of the challenge of establishing a national prevention goal is that water quality issues are site specific, and federal actions benefit from local input about priorities and site-specific conservation strategies. However, local priorities and site-specific approaches that each agency deems appropriate could be reflected in plans to achieve a prevention goal established by the working group. By developing a national goal for the group to focus on preventing HABs and hypoxia, the working group, under the leadership of EPA and NOAA,

[73]The working group has included descriptions of agency efforts to prevent HABs and hypoxia in several of its reports, including the 2016 Research Plan and Action Strategy and its associated 2018 progress report, as well as the 2017 Great Lakes regional plan and its associated 2020 progress report.

[74]The working group's 2021 Planning Document for Coordination updated some information from the 2016 Research Plan and Action Strategy, such as agency roles and responsibilities, but it did not include any updates to the five recommended goals established in the 2016 document.

[75]See, for example, GAO-12-1022 and GAO-14-220.

could help to increase federal attention on prevention actions to reduce the risks that HABs and hypoxia pose to state, local, and tribal communities.

Federal Agencies Have Developed Limited Cost and Benefit Information to Help Select Among Mitigation, Control, and Prevention Actions

Federal agencies in the working group have developed limited information to help state, local, and tribal governments, as well as other entities, compare the costs and benefits of different actions they might take to mitigate, control, or prevent the impacts of HAB and hypoxia events. For example:

- EPA produced a report in 2015 compiling cost information for nutrient reduction projects for freshwater HABs.[76] In particular, the report provides information on the cost of not taking action to control nutrients; such information can help state, local, and tribal leaders compare potential prevention projects.[77]
- NOAA co-sponsored two workshops in 2020 and 2021 that addressed topics related to the socioeconomic impacts of HABs.[78] The 2020 workshop focused on the socioeconomic effects of marine and freshwater HABs in the U.S. and recommended ways to further research on this topic.[79] The 2021 workshop aimed to enhance HAB preparedness and response capabilities of federal and state agencies, and it included discussions of costs associated with HAB responses

[76]Environmental Protection Agency, Office of Water, *A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution* (Washington, D.C.: May 2015).

[77]EPA officials told us that the most difficult part of estimating the costs and benefits of mitigation and control actions is understanding the impacts of these methods on aquatic ecosystems, especially in the medium to long term.

[78]NOAA also contributed to an international workshop on the economic impacts of HABs on wild and farmed fisheries in 2019. For more information on this workshop, see Vera L. Trainer (Ed.), GlobalHAB, *Evaluating, Reducing and Mitigating the Cost of Harmful Algal Blooms: A Compendium of Case Studies* (North Pacific Marine Science Organization: November 2020).

[79]For more information on the 2020 workshop, see U.S. National Office for Harmful Algal Blooms, Woods Hole Oceanographic Institution, *Proceedings of the Workshop on the Socio-economic Effects of Marine and Freshwater Harmful Algal Blooms in the United States* (Woods Hole Oceanographic Institution: March 2021).

as well as cost estimates for tests that agencies can use to analyze cyanotoxins.[80]

- NRCS has published general cost and benefit information online to help agricultural producers understand the costs and benefits of conservation practices. This information allows producers to calculate site-specific costs to compare the costs and benefits of different practices, some of which can help to prevent HABs and hypoxia by reducing nutrient pollution. NRCS also published a report in 2016 that included information about the costs and benefits of conservation practices adopted on cropland in the western Lake Erie Basin.[81]

The working group's 2016 Research Plan and Action Strategy stated that a lack of information on the costs and benefits of various response options presents a challenge to implementing mitigation plans in many regions. The working group's subsequent 2018 Report on Interagency Progress and Implementation further identified a need for models of the socioeconomic costs of HAB and hypoxia events, as well as information to characterize the cost-effectiveness of mitigation, control, and prevention actions to support decision makers and inform prioritization of responses.

State officials in our discussion groups told us that there is a need for more information on the economic impacts of HABs and responses to HABs, which include mitigation, control, and prevention actions. For example, an official from Texas said that there is a need for a sustained effort to describe the economic impacts of HABs on communities. An official from Mississippi said that the federal government could help by developing guidance for states so they can determine when closures of waters are necessary to prevent people from eating seafood from areas exposed to HAB toxins. Closures of shellfish harvesting areas can impact the livelihood of growers, workers, supermarkets, and restaurants, among other economic losses, according to EPA. As a result, providing information on the costs and economic impacts associated with such actions could help inform decision makers responsible for responding to HAB events.

[80]For more information on the 2021 workshop, see Coastal Response Research Center, *Proceedings of the Harmful Algal Bloom (HAB) Preparedness and Response Virtual Workshop and Tabletop Exercise* (Coastal Response Research Center: 2021).

[81]U.S. Department of Agriculture, Natural Resources Conservation Service, *Effects of Conservation Practice Adoption on Cultivated Cropland Acres in Western Lake Erie Basin, 2003-06 and 2012* (March 2016).

NOAA officials told us that federal agencies are still gaining knowledge about the costs of HABs and hypoxia but do not fully understand the costs and benefits of mitigation, control, and prevention actions. The development of more cost and benefit information by federal agencies could help the working group make progress toward its goal from the 2016 Research Plan and Action Strategy to develop a better understanding of the socioeconomic impacts of HABs and hypoxia. Federal agencies may also have opportunities to coordinate with external entities, such as state agencies, tribes, and academics, in developing this cost and benefit information. Our review of academic literature found that such information could include better data on HAB events and information on the costs and benefits to society resulting from these events. This could include the costs of events and of various options to manage and respond to events, such as for mitigating, controlling, or preventing events (see app. III).[82]

According to leading practices for enterprise risk management, federal agencies should consider the costs and benefits of options and communicate the risks with stakeholders.[83] Key stakeholders responsible for responding to HAB and hypoxia events and managing the risks associated with these events include state, local, and tribal governments. Developing more comprehensive information on the costs and benefits of response actions, such as closing down waters to prevent shellfish harvesting, would help inform these stakeholders and allow them to better assess their options for responding to HAB and hypoxia events. This information could also assist in selecting and prioritizing different responses, as described in working group reports.

EPA officials stated that developing such cost and benefit information is important but that doing so is an expensive, time-consuming, and complex effort that goes beyond the agency's staff and resource capacity. In light of these constraints, the officials said that coordinating with other agencies and outside groups to obtain the expertise needed to develop cost and benefit information could help to move this effort forward. NOAA officials stated that they intend to develop such information for control technologies in coastal waters. By coordinating the development of a

[82]As discussed in appendix III, we conducted a literature review and found that assessments on the socioeconomic effects of HABs are wide reaching and that estimates varied by context and method, but a comprehensive national assessment on the costs of HABs has not yet been conducted. We also identified areas for additional research.

[83]GAO-17-63.

more comprehensive body of information on the costs and benefits of mitigation, control, and prevention actions, the working group, under the leadership of EPA and NOAA, could bolster state, local, and tribal efforts to respond to HAB and hypoxia events.

Conclusions

Through their research and other actions to understand and manage the risks of HABs and hypoxia, federal agencies in the working group have increased their knowledge about these complex problems and the harm they can cause to people and the environment. The agencies have also increased their capabilities to monitor and forecast certain types of blooms in some areas of the country, particularly in coastal environments. In addition, federal agencies in the working group have provided important support, such as technical assistance and funding, to help state, local, and tribal governments respond to HAB and hypoxia events.

However, federal efforts have been limited in several ways that make it more difficult for federal and nonfederal entities to effectively respond to HAB and hypoxia events and to manage the risks associated with these events. As co-chairs of the working group, NOAA and EPA have not defined what a national HAB and hypoxia program would entail, but doing so would better position them to implement the program under the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, as amended. The working group also has not developed performance measures to assess the results of federal efforts to manage the risks of HABs and hypoxia, including assessing progress toward achieving the recommended goals from its 2016 Research Plan and Action Strategy. In addition, federal agencies in the working group have taken limited actions to monitor and forecast freshwater HAB and hypoxia events. Developing interagency frameworks for expanding monitoring and forecasting of freshwater HAB and hypoxia events would better position EPA and the working group to obtain the information needed to manage the risks from such events.

Furthermore, preventing HABs and hypoxia needs increased attention at the federal level. While the working group has described agencies' prevention efforts in its reports, the group did not include prevention among the five goals for federal research and actions it established in its 2016 Research Plan and Action Strategy. At the same time, limited availability of information on the costs and benefits of mitigation, control, and prevention actions may hamper the ability of state, local, and tribal governments to determine the best way to respond to HAB and hypoxia events. By coordinating the development of a more comprehensive body of cost and benefit information, the working group could help states, localities, and tribes improve their response.

By addressing these limitations, NOAA and EPA, in collaboration with the other members of the working group, would enhance federal efforts to manage the risks of HAB and hypoxia events and better position federal agencies to support state, local, and tribal governments responding to these events.

Recommendations for Executive Action

We are making a total of six recommendations, including two to EPA and four to NOAA and EPA as the co-chairs of the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act.

The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should document and define what a national HAB and hypoxia program would entail, including identifying the program’s resource needs. (Recommendation 1)

The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should develop performance measures to assess the working group’s efforts, including the extent to which the recommended goals from the Research Plan and Action Strategy have been achieved. (Recommendation 2)

The Administrator of EPA, working with the other members of the working group, should develop an interagency framework, including prioritizing water bodies and identifying resource needs, to expand monitoring of freshwater HABs and hypoxia. (Recommendation 3)

The Administrator of EPA, working with the other members of the working group, should develop an interagency framework, including prioritizing water bodies and identifying resource needs, to expand forecasting of freshwater HABs and hypoxia. (Recommendation 4)

The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should develop a national goal for the group focused on efforts to prevent HABs and hypoxia. (Recommendation 5)

The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should coordinate the development of a more comprehensive body of information on the costs and benefits of mitigation, control, and prevention actions for use by state, local, and tribal governments. (Recommendation 6)

Agency Comments

We provided a draft of this report for review and comment to the Departments of Agriculture, Commerce, Defense, Health and Human Services, Homeland Security, the Interior, and State; EPA; NASA; the National Science Foundation; and the Office of Science and Technology Policy. Commerce's NOAA and EPA provided written comments, which are reproduced in appendixes VII and VIII, respectively. The Departments of Homeland Security and State, as well as NASA and the Office of Science and Technology Policy, responded by email that they did not have comments on the draft report. The Departments of Agriculture, Defense, Health and Human Services, and the Interior, as well as NOAA, EPA, and the National Science Foundation, provided technical comments, which we incorporated as appropriate.

NOAA and EPA agreed with all of our recommendations but expressed concern that authority and resource limitations may affect their ability to implement two of them. For the recommendation to define what a national HAB and hypoxia program would entail and identify its resource needs, the agencies stated that neither has specific authorities to oversee activities carried out by the other member agencies of the working group. EPA also mentioned that neither agency has direct appropriations for the working group. Rather than oversee other member agencies' activities, however, our recommendation calls for NOAA and EPA, as co-chairs of the working group, to define a national program in collaboration with those agencies. Furthermore, as co-chairs, the agencies are best positioned to identify any additional resources that may be needed to carry out the program.

Similarly, for the recommendation to coordinate the development of a more comprehensive body of information on the costs and benefits of mitigation, control, and prevention actions, EPA stated that the working group does not have the funding to do so for all existing actions. EPA said that the group would need additional resources from Congress. We recognize that the agencies cannot conduct all the work themselves, which is why our recommendation calls for them to coordinate on this effort. As appropriate, such coordination could also involve outside entities and build upon existing efforts to determine the costs and benefits of different actions. If the agencies find that they need additional resources to accomplish this, they could identify these resource needs, perhaps as part of identifying the resources needed to implement the national program.

We are sending copies of this report to the appropriate congressional committees; the Secretaries of the Departments of Agriculture, Commerce, Defense, Health and Human Services, Homeland Security, the Interior, and State; the Administrators of EPA and NASA; the Director of the National Science Foundation; the Acting Director of the Office of Science and Technology Policy; and other interested parties. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions concerning this report, please contact me at (202) 512-3841 or gomezj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix IX.

J. Alfredo Gómez
Director, Natural Resources and Environment

List of Requesters

The Honorable Roger Wicker
Ranking Member
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Eddie Bernice Johnson
Chairwoman
The Honorable Frank Lucas
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

The Honorable Mikie Sherrill
Chairwoman
The Honorable Stephanie Bice
Ranking Member
Subcommittee on Environment
Committee on Science, Space, and Technology
House of Representatives

The Honorable Suzanne Bonamici
House of Representatives

The Honorable Charlie Crist
House of Representatives

The Honorable Marcy Kaptur
House of Representatives

The Honorable Bill Posey
House of Representatives

The Honorable Abigail D. Spanberger
House of Representatives

The Honorable Michael Waltz
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report examines (1) the extent to which the Interagency Working Group on the Harmful Algal Bloom (HAB) and Hypoxia Research and Control Act (working group) has implemented a national HAB and hypoxia program and assessed the results of federal efforts to manage the risks of HABs and hypoxia; (2) actions that federal agencies in the working group have taken to monitor and forecast HAB and hypoxia events; and (3) actions that federal agencies in the working group have taken to help state, local, and tribal governments respond to HAB and hypoxia events. As of November 2021, working group agency co-chairs and members include the following:

- Department of Commerce, specifically, the National Oceanic and Atmospheric Administration (NOAA)—co-chair;
- Environmental Protection Agency (EPA)—co-chair;
- White House Office of Science and Technology Policy—co-chair, but vacant;[1]
- Department of Agriculture, specifically the Agricultural Research Service, National Institute of Food and Agriculture, and Natural Resources Conservation Service;
- Department of Defense, specifically the Department of the Navy and U.S. Army Corps of Engineers;
- Department of Health and Human Services, specifically the Centers for Disease Control and Prevention, Food and Drug Administration, and the National Institute of Environmental Health Sciences;
- Department of Homeland Security, specifically the U.S. Coast Guard;
- Department of the Interior, specifically the Bureau of Indian Affairs, U.S. Fish and Wildlife Service, National Park Service, and U.S. Geological Survey;
- National Aeronautics and Space Administration;
- National Science Foundation;
- State Department; and

[1]The White House Office of Science and Technology Policy is also identified in working group documentation as an additional co-chair that provides oversight of the group's direction and activities, publishes documents produced by the working group, and submits such documents to Congress. However, as of October 2021, there was no official co-chair representative from the office serving on the working group.

- White House Council on Environmental Quality.

To address these objectives, we reviewed relevant laws, analyzed agency and working group documents and reports related to HAB and hypoxia initiatives, and interviewed officials from 18 member agencies of the working group.[2] To obtain a breadth of perspectives on the human health, environmental, and economic risks of HABs and hypoxia, we also interviewed knowledgeable stakeholders, whom we identified through a targeted internet search and snowball sampling approach.[3] We conducted 12 semistructured interviews with representatives from five nongovernmental organizations, three water sector groups, and four academic institutions. Because this is a nongeneralizable sample, the results of these interviews do not represent the views of all stakeholders involved in HAB and hypoxia issues. However, they illustrate a range of perspectives on these topics.

To examine the extent to which the working group has implemented a national HAB and hypoxia program and has assessed the results of federal efforts to manage the risks of HABs and hypoxia, we reviewed working group reports and documents and interviewed working group co-chairs NOAA and EPA about the working group's coordination, strategic planning, and performance management. We also interviewed working group members about participation in the working group and how well the group coordinates. We assessed the working group's activities against the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, as amended; GAO's leading practices for collaboration and performance management and reporting; and the Project Management Institute's leading practices for program management.[4]

[2]We interviewed officials from all working group member agencies, except for the White House Council on Environmental Quality and the Bureau of Indian Affairs. According to a Council on Environmental Quality official, the council's role in the working group is minor because the issues are more science focused than policy focused. We did not interview officials from the Bureau of Indian Affairs because the agency was recently named to the working group.

[3]Through the snowball sampling approach, we asked representatives of each stakeholder organization to propose or recommend additional stakeholders for us to interview.

[4]Pub. L. No. 105-383, tit. VI, 112 Stat. 3447 (codified as amended at 33 U.S.C. §§ 4001-4010); GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012); *Managing for Results: Implementation Approaches Used to Enhance Collaboration in Interagency Groups*, GAO-14-220 (Washington, D.C.: Feb. 14, 2014); and Project Management Institute, Inc., *The Standard for Program Management*, Fourth Edition, 2017.

To examine the actions that federal agencies have taken to monitor and forecast HAB and hypoxia events and to help state governments respond to these events, we obtained perspectives from state officials by conducting virtual small group discussion sessions. To gather participants, we invited officials from all 50 states and the District of Columbia that EPA and NOAA identified as having been involved in managing each state's response to HABs and hypoxia. We also invited state officials who are members of the Association of Clean Water Administrators and Association of State Drinking Water Administrators.[5] We developed a list of all officials who volunteered and then randomly placed each participant into a session, unless such placement would have meant having more than one member from the same state in the discussion group.[6] A GAO moderator facilitated the group sessions. In total, we conducted seven 90-minute sessions virtually in April 2021.

Each discussion group had from four to nine state officials representing different states—in all, we spoke with 49 officials from 37 states.[7] During each discussion group, the GAO moderator asked state officials to discuss three key topics:

1. Key challenges states face in managing the risks of HABs and hypoxia;

[5]The Association of Clean Water Administrators is a national, nonpartisan professional organization made up of state, interstate, and territorial officials who are responsible for the implementation of surface water protection programs throughout the nation. The Association of State Drinking Water Administrators is a professional association made up of drinking water program administrators in the 50 states, the five territories, the Navajo Nation, and the District of Columbia.

[6]While we generally included only one official from each state, there were some states (California, Florida, Louisiana, Mississippi, Oregon, Rhode Island, Texas, Vermont, and Virginia) from which more than one official participated because the officials represented different state agencies that have different roles in managing HABs or hypoxia. For example, we included officials from two Rhode Island state agencies—the Department of Health and the Department of Environmental Management—in different discussion groups because these officials provided different perspectives, given their different purviews with regard to managing HABs. However, no group had more than one official from the same state.

[7]The states and district that participated in the discussion groups were Alaska, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Hawaii, Idaho, Indiana, Iowa, Kansas, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, New Hampshire, New Jersey, New York, North Carolina, North Dakota, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Utah, Vermont, Virginia, Washington, Washington, D.C., and Wisconsin.

2. Federal agencies' roles in working with states to manage the risks of HABs, hypoxia, or both, including identifying, assessing, responding, monitoring, communicating, and reporting on risks; and
3. Actions federal agencies can take to help states address the key challenges and how these actions would improve states' management of HABs and hypoxia.

We developed a written summary for each discussion group. To do so for each session, our team members served on a rotating basis as the designated note-taker, back-up note-taker, or co-moderator. We also saved all information inputted by participants in the virtual chat window during each session. The designated note-taker then used their notes, the back-up notes, and chat transcripts to prepare each written summary.

We conducted a content analysis of the written summaries to identify categories and subcategories for the three key topics. To prepare for this analysis, two analysts independently reviewed the first three discussion group summaries and developed initial lists of categories and subcategories. These analysts next compared and reconciled their lists to develop one agreed-upon list of categories and subcategories, which they applied to the content of all seven summaries. Each separate issue raised by state officials was assigned to an existing category, unless the issue did not relate to any of the existing categories, in which case we created a new category. The analysts ultimately created 12 categories and 49 subcategories. To code, one analyst applied the list of categories to each of the seven discussion summaries. A second analyst reviewed the coding results for agreement. When there was a difference in coding, the two analysts discussed the categories to reach a resolution. We cannot generalize the information obtained through this small group method to other states or state officials that did not participate, but we did find common themes and illustrative examples within and across our groups.

We assessed the federal agencies' actions to monitor and forecast HAB and hypoxia events against goals stated in the working group's 2016 Research Plan and Action Strategy and GAO's leading practices for enterprise risk management. These practices include assessing risks and monitoring how they are changing to select appropriate risk responses.[8]

[8]GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risk*, GAO-17-63 (Washington, D.C.: Dec. 1, 2016).

To examine the actions that federal agencies have taken to help local and tribal governments respond to HAB and hypoxia events, we also interviewed officials from selected local and tribal governments. To identify officials with experience addressing, managing, or responding to HABs and hypoxia, we asked participants in our discussion groups to suggest local and tribal contacts who might talk with us about their experiences interacting with federal agencies. Among these recommended contacts, we judgmentally selected interviewees according to geographic diversity. Specifically, we selected one locality and one tribe per Census region and did not select representatives from localities and tribes located in the same state.[9] In instances where multiple localities or tribes were recommended in one Census region, we used a random number generator to select entities to interview. Using these criteria, we selected local and tribal representatives for interviews from the Midwest, Northeast, South, and West regions.[10] Because this is a nongeneralizable sample, the results of these interviews may not represent the views of all local and tribal officials involved in responding to HAB and hypoxia events. However, they provided illustrative examples.

We assessed working group actions to assist state, local, and tribal governments against goals in the 2016 Research Plan and Action Strategy, as well as GAO leading practices for collaboration and enterprise risk management. Specifically, we assessed working group actions against the GAO leading practices that call for interagency collaborative efforts to establish clear, shared goals and for federal agencies to consider the costs and benefits of risk management options and communicate them to stakeholders.[11]

Finally, we reviewed socioeconomic literature, the results of which are presented in appendix III. For the review, we selected all articles using the bibliography compiled by the experts in a 2021 report on a workshop held in 2020 on the socioeconomic effects of marine and freshwater

[9]According to the U.S. Census Bureau, Census regions are the Midwest, Northeast, South, and West.

[10]Specifically, we spoke with local government representatives from Florida, Iowa, Oregon, and Vermont, and we spoke with tribal government representatives from California, Maine, Minnesota, and Mississippi.

[11]See GAO-12-1022, GAO-14-220, and GAO-17-63.

HABs in the U.S.[12] We also selected articles from a 2018 summary of existing literature on assessing the economic consequences of HABs.[13] We then used Google Scholar and EBSCO (an online reference center on scholarly, trade, and news articles on business, management, and economics) to identify peer-reviewed quantitative studies published after the workshop that examined the costs and benefits of mitigation, control, and prevention strategies.[14] This review was not exhaustive, as socioeconomic studies on HABs date back to the 1970s, and we did not review articles published prior to 2000.

We conducted this performance audit from September 2020 to June 2022 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[12]U.S. National Office for Harmful Algal Blooms, Woods Hole Oceanographic Institution, *Proceedings of the Workshop on the Socio-economic Effects of Marine and Freshwater Harmful Algal Blooms in the United States* (Woods Hole Oceanographic Institution: March 2021).

[13]Charles M. Adams et al., "Assessing the Economic Consequences of Harmful Algal Blooms: A Summary of Existing Literature, Research Methods, Data, and Information Gaps," *Harmful Algal Blooms: A Compendium Desk Reference* (2018), 337-354.

[14]We reviewed 26 studies on marine HABs and 15 on freshwater HABs.

Appendix II: Hypoxia in U.S. Waters and Federal Activities to Manage It

Hypoxia is a serious environmental condition that can affect fisheries and ecosystems by reducing the extent and quality of habitat for aquatic organisms, according to a 2010 report by the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (working group).[1] In the early 1980s, concern about low dissolved oxygen in coastal water bodies of the U.S. led to the first national assessment of hypoxia in U.S. water bodies. By the 1990s, serious and large-scale water quality problems were identified, including harmful algal blooms (HAB) and hypoxia, most prominently in the northern Gulf of Mexico, Lake Erie, Chesapeake Bay, and Long Island Sound. This appendix describes the causes and extent of hypoxia in U.S. water bodies; what is understood about it; and federal efforts to monitor, assess, and prevent it.

Causes and Extent of Hypoxia in U.S. Waters

Hypoxia refers to waters that have low dissolved oxygen, a condition that stresses aquatic life in lakes, estuaries, and marine waters. It is caused by a complex mix of biological, chemical, and physical factors.

The 2010 working group report found that widespread and persistent hypoxia is generally not a natural condition in estuaries, coastal waters, or large lakes like the Great Lakes, with Lake Erie being an exception.[2] The report identified the principal cause of hypoxia as eutrophication, which is defined as "an increase in the rate of supply of organic matter to an ecosystem" that causes increased use of oxygen in the water. Eutrophication often results from nutrient discharge from urban and

[1]Committee on Environment and Natural Resources, *Scientific Assessment of Hypoxia in U.S. Coastal Waters* (Washington, D.C.: Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology, 2010). The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 called for the establishment of the Interagency Task Force on Harmful Algal Blooms and Hypoxia but also allowed for the disestablishment of the task force. Pub. L. No. 105-383, § 603(a), (e), 112 Stat. 3447, 3448. The 2004 amendments to the act called for the retention of the task force by striking the provision allowing for its disestablishment. Pub. L. No. 108-456, § 102, 118 Stat. 3630, 3630. According to the 2010 report, in order to fulfill requirements of the 2004 act and other requirements, the task force was incorporated into the already existing Interagency Working Group on HABs, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. That task force fulfilled those requirements of the 2004 act with five reports issued from 2007 through 2010 and then disbanded until the 2014 reauthorization of the act. The working group was reconstituted again after the 2014 amendments to the act. *See* Pub. L. No. 113-124, 128 Stat. 1379.

[2]For additional updated information on human-derived and naturally occurring hypoxia in the Great Lakes, see Joshua M. Tellier et al., "Widespread Prevalence of Hypoxia and the Classification of Hypoxic Conditions in the Laurentian Great Lakes," *Journal of Great Lakes Research*, vol. 48 (2022): 13-23.

agricultural land runoff, wastewater treatment plant discharges, and air deposition of nutrients. Eutrophication, combined with other environmental stressors such as HABs, continues to degrade U.S. waters.[3]

Marine hypoxia can also result from ocean conditions, apart from eutrophication, according to the 2010 working group report. Coastal waters are often stratified into layers based on salinity and temperature; in many coastal areas, colder, more saline water is denser and may not mix with less saline, warmer water. Such stratification reduces the potential for oxygen from the atmosphere to replenish oxygen depleted at lower levels. In addition, warmer surface water temperatures can also contribute to density stratification in marine systems, especially during the spring, when deeper waters are relatively cold.

U.S. Water Bodies Experiencing Hypoxia

Federal agencies have been researching hypoxia since the 1980s and have issued several reports on the extent of hypoxia in coastal and freshwater bodies in the U.S.[4] For example, the 2010 working group report determined that hypoxia in coastal waters of the U.S. had increased to 300 locations from 12, beginning in the early 1960s and continuing through the 1980s. The report also showed that zones with hypoxia exist in the Chesapeake Bay, the Northeast and Northwest Coasts, and the Great Lakes. It also stated that the Gulf of Mexico is the second-largest hypoxic zone in the world.

The following describes several key water bodies that experience hypoxia:

Chesapeake Bay, a large water body with six states in its watershed (Delaware, Maryland, New York, Pennsylvania, Virginia, and West

[3]Algal blooms, including harmful algal blooms, can exacerbate hypoxia by dying and decaying, causing oxygen use and depletion. Hypoxia is not always directly related to algal blooms and HABs, however.

[4]See S. Bricker et al., *National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries* (Silver Spring, MD: National Oceanic and Atmospheric Administration, 1999); Committee on Environment and Natural Resources, *An Assessment of Coastal Hypoxia and Eutrophication in U.S. Waters* (Washington, D.C.: National Science and Technology Council, 2003); Committee on Environment and Natural Resources, *Scientific Assessment of Hypoxia in U.S. Coastal Waters* (2010); and T. E. Whitledge, *Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters: Northeast Region* (Rockville, MD: Report to U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, 1985).

Virginia, as well as the District of Columbia), experiences hypoxia regularly, according to the Virginia Institute of Marine Science. The 2010 working group report described it as consisting of broad shallow areas that flank a deeper central channel. It also receives water from many rivers draining into it. These features cause the water in the bay to be stratified and to limit mixing. The Bay is subject to an interagency and interstate ecosystem restoration effort, with federal efforts led by the Environmental Protection Agency (EPA).

The Gulf of Mexico hypoxic zone off the coasts of Louisiana and Texas is the largest in the U.S., according to the 2010 working group report. The 2021 Gulf hypoxia zone, which scientists measured to be approximately 6,334 square miles, is equivalent to more than 4 million acres of habitat potentially unavailable to fish and bottom species. The zone occurs west of the Mississippi River Delta. The Mississippi and Atchafalaya Rivers are the main source of freshwater, nutrients, and sediment in the northern Gulf. The Gulf hypoxic zone has been monitored for at least 3 decades and, in 1998, EPA established a Mississippi River/Gulf of Mexico Watershed Nutrient Task Force to consider options for reducing, mitigating, and controlling hypoxia in the area. In 2001, the task force developed an action plan for reducing hypoxia, which it updated in 2008. The federal members of the task force developed a federal strategy in 2016. While these efforts have reduced nutrient inputs into the Gulf, the size of the hypoxic zone has not decreased.

Hood Canal is a natural formation, a subbasin of Puget Sound in Washington State that has experienced hypoxia periodically dating back centuries, according to the 2010 working group report. It features a natural sill at its mouth that restricts circulation with greater Puget Sound, resulting in slow circulation. Hypoxia has increased in the canal since the 1990s, leading to fish kills and closure of fishing areas. A partnership of 28 organizations, including the National Oceanic and Atmospheric Administration (NOAA), EPA, the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers, and the U.S. Navy, as well as a variety of nonfederal entities, was formed in 2005 to study oxygen dynamics in the canal. In addition, the Puget Sound Partnership, a state effort, is managing restoration of the larger Puget Sound.

Lake Erie, the shallowest of the five Great Lakes, experiences annual hypoxia in late summer and early fall, according to the 2010 working group report. It has a natural tendency to develop hypoxia that is exacerbated by large nutrient discharges from its tributaries. Invasive zebra mussels, which arrived in the 1980s, have also caused ecological change and may be contributing to hypoxia. The lake is subject to ongoing monitoring and research by federal agencies. It is also part of the Great Lakes Restoration Initiative, an interagency effort managed by EPA.

Long Island Sound, an estuary shared by Connecticut and New York, experiences annual summertime hypoxia in its western half, near New York City. Since 1985, the estuary has been the subject of intensive monitoring, modeling, and research through the Long Island Sound Study, an interagency effort managed by EPA as part of the National Estuary Program. According to the 2010 working group report, despite significant reductions in nitrogen loads by both Connecticut and New York under a total maximum daily load (TMDL) approved in 2001, dissolved oxygen improvements have been slow and masked by weather-driven variability and the effects of climate change.[5]

Federal Efforts to Monitor and Assess Hypoxic Zones

Federal agencies are involved in efforts to monitor and assess marine and freshwater bodies for hypoxia in certain regions, particularly the Gulf of Mexico and the Great Lakes. According to the 2010 working group report, identifying and assessing the causes of hypoxia depend heavily upon monitoring programs and the development of models.

The monitoring of dissolved oxygen and, therefore, hypoxia conditions, in coastal waters is usually conducted as a component of research and water quality monitoring programs. According to the 2010 working group report, many such programs are conducted through partnerships involving federal agencies, states, and local governments. EPA's National Estuary Program supports such partnerships around the country in order to implement environmental monitoring. As part of their respective missions, EPA and USGS also conduct long-term assessments of environmental and ecological conditions, including dissolved oxygen, within selected coastal waters. The Integrated Ocean Observing System, managed by NOAA, seeks to collect and integrate regional ocean and coastal data, including dissolved oxygen, into a national monitoring framework. In addition, NOAA's Great Lakes Environmental Research Laboratory also conducts regular monitoring, according to NOAA officials.

[5]A TMDL is a pollutant budget or target for the amount of a pollutant that can be discharged into a water body while still meeting water quality standards. See GAO, *Clean Water Act: Changes Needed If Key EPA Program Is to Help Fulfill the Nation's Water Quality Goals*, GAO-14-80 (Washington, D.C.: Dec. 5, 2013).

The monitoring of two hypoxic zones that occur in federal waters is also ongoing. First, routine monitoring of dissolved oxygen occurs as part of surveys of salmon from Oregon to the Canadian border along the Northeast Pacific Continental Shelf. Such monitoring began in 2006 in order to track the ocean currents that have caused periodic hypoxia off the coast of Oregon. The shelf receives nutrients from coastal currents and the Columbia River and, as a result, the shelf's hypoxia is due to natural sources and is, therefore, unique.

Second, monitoring surveys in the northern Gulf of Mexico have occurred annually since 1985.[6] NOAA has supported ship-based monitoring and, more recently, autonomous underwater vehicles, or gliders, for enhanced monitoring of seasonal hypoxia in the northern Gulf of Mexico. NOAA has also deployed several moored instrument arrays in the Gulf of Mexico hypoxic zone to obtain continuous records of dissolved oxygen. Efforts to improve and test the moored instruments are ongoing. These monitoring efforts have provided the principal metric for assessing progress toward the goal of a reduction in hypoxia outlined by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force.

Other sampling of water quality (including dissolved oxygen) on the continental shelf and near major outlets of the Mississippi and Atchafalaya Rivers occurs annually and seasonally as a part of shelf-wide surveys and hypoxia-related research by NOAA and EPA. These surveys were designed to quantify key physical and biogeochemical processes influencing the development and persistence of hypoxia and to support the development of predictive models.[7]

Federal Efforts to Forecast Hypoxia

In addition to federal efforts to monitor marine and certain freshwater bodies for hypoxia, NOAA annually develops forecasts for some hypoxia zones. Hypoxia forecasts aim to provide coastal managers and stakeholders with the information needed (1) to take proactive action to

[6]For example, the Gulf of Mexico hypoxia monitoring cruise is an annual shelf-wide survey of the Gulf's hypoxic area. The survey is the metric used by the interagency Mississippi River/Gulf of Mexico Watershed Nutrient Task Force to assess progress toward achieving its goal of mitigating hypoxia. Except for in 1989 and 2016, this survey has been conducted annually since 1985 and represents one of the longest ecological datasets on record. For more information, see https://coastalscience.noaa.gov/project/operational-gulf-of-mexico-hypoxia-monitoring/.

[7]"Biogeochemical" refers to the cycling of chemicals and compounds between living and nonliving parts of an ecosystem.

mitigate the impacts of an ongoing hypoxic event and (2) to set nutrient reduction targets to reduce the magnitude of future events. NOAA has funded the development of hypoxia forecasts in the Gulf of Mexico since 1990 and in the Chesapeake Bay since 2005. EPA has also developed two models to simulate hypoxia in the northern Gulf of Mexico. In addition, NOAA's Great Lakes Environmental Research Laboratory has developed an experimental forecast for Lake Erie's hypoxic zone.

Federal Efforts to Prevent Hypoxia

The working group issues progress reports on federal hypoxia efforts.[8] The reports include updates on federal research efforts, as well as federal assistance for preventing hypoxia by managing nutrients that can contribute to it.

The working group's 2018 progress report identified federal efforts to develop information on nutrient management in the Mississippi River Basin related to the hypoxic zone in the Gulf of Mexico. For example, the U.S. Department of Agriculture (USDA) examines the effects of existing conservation activities on water quality and soil resources in edge-of-field and large river basins, such as the Mississippi River Basin and the Great Lakes. USDA has also estimated needs for conservation treatments to reduce nutrients discharged into such ecosystems. Further, USDA's Agricultural Research Service and Natural Resources Conservation Service conduct edge-of-field and instream monitoring in nine small watersheds throughout the Basin to support the Conservation Effects Assessment Project. The project seeks to understand the changes to water quality that result from implementing conservation practices.

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force also reports on federal and state efforts to reduce nutrients discharged into the Gulf. For example, the task force reported in 2017 that Mississippi River Basin states have developed nutrient management plans and that federal agencies provide tools to assess water quality improvements associated with the implementation of these plans.[9]

[8]For example, see Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the United States: A Report on Interagency Progress and Implementation* (Washington, D.C.: Mar. 5, 2018); and *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Repor*t (November 2020).

[9]Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, *2017 Report to Congress* (Washington, D.C.: August 2017). Federal agencies have also directly funded nutrient reduction approaches and projects in the Basin.

In addition, the working group's 2020 Great Lakes progress and implementation report identified nutrient management projects in the Great Lakes Basin. For example, the report noted that federal and state agencies and their partners, using the Great Lakes Restoration Initiative and other funding, supported nutrient and sediment reduction projects on over 105,000 acres in targeted watersheds in the Great Lakes Basin in 2019. The agencies estimated that more than 400,000 pounds of phosphorus were reduced in fiscal year 2019 and 1.5 million pounds from fiscal years 2015 through 2019.[10]

[10]Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act, *Harmful Algal Blooms and Hypoxia in the Great Lakes: An Interagency Progress and Implementation Report* (November 2020).

Appendix III: Summary of the Socioeconomic Effects of Harmful Algal Blooms

This appendix summarizes our review of peer-reviewed quantitative studies published since 2000 on the socioeconomic effects of harmful algal blooms (HAB). Overall, we found that assessments on the socioeconomic effects of HABs are wide reaching and that estimates varied by contexts and methods, but we did not find a comprehensive national assessment on the costs of HABs. The socioeconomic effects of HABs include commercial, recreational, and subsistence fishery closures and harvest delays; reduced tourism and recreation demand; lower property prices; avoidance of seafood consumption; and increased costs of both drinking water treatment and health care.

We identified two studies that estimated nationwide costs associated with HABs, but they were limited and demonstrated widely different estimates—$50 million annually for marine HABs only, and $2.2 billion annually for freshwater HABs.[1] We found that local estimates varied by regional economic sectors examined and the characteristics of the HAB event. The local estimates that we reviewed identified HAB-related costs ranging from $3 million in single counties for recreation and tourism to $18 million in one state for recreational and commercial fisheries and $142 million annually for Lake Erie for various sectors.

Scope and Method

For this review, we selected all articles using the bibliography compiled by the experts in a 2021 report on a workshop held in 2020 on the socioeconomic effects of marine and freshwater HABs in the U.S.[2] We also selected all the articles in a 2018 summary of existing literature on assessing the economic consequences of HABs.[3] We then used Google Scholar and EBSCO (an online reference center on scholarly, trade, and news articles on business, management, and economics) to identify peer-reviewed quantitative studies published after the workshop that examined

[1]Estimated dollar values hereafter are quoted as reported in the reviewed studies. We do not adjust for inflation. See Porter Hoagland et al., “The Economic Effects of Harmful Algal Blooms in the United States: Estimates, Assessment Issues, and Information Needs,” *Estuaries,* vol. 25, no. 4 (2002): 819-837; and Walter K. Dodds et al., “Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages,” *Environmental Science and Technology,* vol. 43, no. 1 (2009): 12-19.

[2]U.S. National Office for Harmful Algal Blooms, Woods Hole Oceanographic Institution, *Proceedings of the Workshop on the Socio-economic Effects of Marine and Freshwater Harmful Algal Blooms in the United States* (Woods Hole Oceanographic Institution: March 2021).

[3]Charles M. Adams et al., “Assessing the Economic Consequences of Harmful Algal Blooms: A Summary of Existing Literature, Research Methods, Data, and Information Gaps,” *Harmful Algal Blooms: A Compendium Desk Reference* (2018), 337-354.

the costs and benefits of mitigation, control, and prevention strategies.[4] This review is not exhaustive—socioeconomic studies on HABs date back to the 1970s, and we did not review articles published prior to 2000.

The studies we reviewed applied existing economic methods and combined observations or predictions of HABs with changes in prices, outputs, expenditures, and human behavior and preferences in affected sectors and communities to estimate the dollar values of the HAB effects. The typical methods included economic impact analysis and nonmarket valuation methods.[5] Most studies focused on the immediate losses following HABs, and only a few studies predicted losses more than 20 to 30 years in the future.

National Estimates Are Limited

We found two national-level assessments that estimated various socioeconomic effects of HABs, but the assessments were limited by available data and the complexity and variability of HAB effects by region and economic sector. One study used marine HAB occurrences reported by state experts to estimate that the annual economic impacts of those marine HABs in the U.S. averaged $50 million annually from 1987 to 1992, including the costs associated with health care, tourism, fisheries, and monitoring.[6] The second study, published in 2009, used the level of eutrophication in U.S. freshwaters to infer the impacts of freshwater

[4]We reviewed 26 studies on marine HABs and 15 on freshwater HABs.

[5]Economic impact studies assess economic impacts by measuring changes in revenue and employment levels in affected sectors (e.g., fishery) and the greater regional economy. “Nonmarket valuation” refers to estimating the monetary values of environmental goods and services that are not traded in a market and, thus, cannot be valued directly through market prices and transactions. One type of nonmarket valuation method uses observations of changes in related market activities, such as recreation demand and property transactions, to measure the loss in economic value of water resources because of HABs (i.e., the revealed preference method). Another type of method directly asks residents about their willingness to pay to avoid HABs (i.e., the stated preference method). Another nonmarket valuation method uses estimated values from one HAB event to infer economic loss from another HAB event (i.e., the benefit transfer method). For more information, see Kevin J. Boyle, Thomas C. Brown, and Patricia A. Champ, eds., *A Primer on Nonmarket Valuation* (Springer Netherlands, 2017).

[6]Porter Hoagland et al., “The Economic Effects of Harmful Algal Blooms in the United States: Estimates, Assessment Issues, and Information Needs,” 819-837. As indicated, the estimates are for the period 1987-1992, but the dollar value was reported in year 2000 dollar values.

HABs.[7] It estimated that nationally, the annual economic loss associated with eutrophication was approximately $2.2 billion in 2001 dollars, including losses from recreation use, waterfront real-estate values, costs for protection and recovery of endangered species, and costs for drinking water treatment.

Regional and Sector-Specific Socioeconomic Effects and Estimates Vary

We found that regional and sector-specific effects and estimates of their costs varied, depending on factors related to the context and nature of the HAB events. These factors included how long HABs were present, the toxins produced, their size and location, and the economic sectors and human population in those locations.

For example, the blooms of *Alexandrium fundyense* in 2005 in New England and *Pseudo-nitzschia* in 2015 in the Pacific Northwest resulted in widespread closure of recreational and commercial shellfish fisheries. The estimated economic impact of the 2005 blooms was $2.4 million in Maine and $18 million in Massachusetts.[8] The 2015 blooms caused a decline of $97.5 million in the harvest of Dungeness crab in the Pacific Northwest compared to the previous season, leading to disaster declarations.[9] In addition, almost $40 million in tourism spending was estimated to be lost for coastal communities in Washington State in 2015. Earlier *Pseudo-nitzschia* blooms in the Pacific Northwest were also found to reduce the labor income in two counties of Washington State by $10.6 million in 2008.[10]

Recent studies further indicated that the negative effects of the 2015 event were not distributed equally across sectors and communities. One

[7]Walter K. Dodds et al., "Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages," 12-19. Eutrophication occurs when a body of water receives an excessive nutrient load, particularly phosphorus and nitrogen. This often results in an overgrowth of algae. As the algae die and decompose, oxygen is depleted from the water, and this lack of oxygen in the water causes the death of aquatic animals, such as fish.

[8]Di Jin, Eric Thunberg, and Porter Hoagland, "Economic Impact of the 2005 Red Tide Event on Commercial Shellfish Fisheries in New England," *Ocean & Coastal Management*, vol. 51, no. 5 (2008): 420-429.

[9]National Oceanic and Atmospheric Administration Fisheries, "Hitting Us Where It Hurts: The Untold Story of Harmful Algal Blooms" (Silver Spring, MD.: Aug. 16, 2021), accessed Sept. 17, 2021, https://www.fisheries.noaa.gov/west-coast/science-data/hitting-us-where-it-hurts-untold-story-harmful-algal-blooms.

[10]Karen Dyson and Daniel D. Huppert, "Regional Economic Impacts of Razor Clam Beach Closures Due to Harmful Algal Blooms (HABs) on the Pacific Coast of Washington," *Harmful Algae*, vol. 9, no. 3 (2010): 264-271.

study found that fishers and communities that experienced longer closures were more vulnerable to HAB risks.[11] Another study found that while retail prices of Dungeness crab were not significantly affected, prices that fishers received fell by as much as 22 to 23 percent.[12] Large vessels (at least 40 feet in length) experienced smaller revenue losses as compared to the loss in revenues from small vessels, since large vessels could mitigate the effects by fishing for other species or in different coastal waters.[13]

In addition to contributing to losses in the shellfish industry, marine HABs were found to reduce economic benefits for recreational boating, lower property values, and increase health care costs. For example, a 2018 HABs event was found to reduce recreational boating benefits by $3 million in one coastal county in Florida.[14] The series of red tides (*Karenia brevis*) in southwest Florida between 2002 and 2018 were shown to reduce prices of properties within 5 miles of the coastline by 10 percent.[15] A sharper decline in prices was observed for properties within 1 mile of the affected coast during blooms in the same region, resulting in an estimated 20.3 percent reduction.[16] Another study estimated that the 2018 red tide event in Florida resulted in the loss of $317 million in sales revenue because of reduced demand in the vacation house rental market and other related effects.[17] Additionally, *Karenia brevis* can become

[11]Stephanie K. Moore et al., “An Index of Fisheries Closures Due to Harmful Algal Blooms and a Framework for Identifying Vulnerable Fishing Communities on the U.S. West Coast,” *Marine Policy*, vol. 110 (2019): 103543.

[12]Junwei Mao and Sunny L. Jardine, “Market Impacts of a Toxic Algae Event: The Case of California Dungeness Crab,” *Marine Resource Economics*, vol. 35, no. 1 (2020): 1-20.

[13]Sunny L. Jardine et al., “Inequality in the Economic Impacts from Climate Shocks in Fisheries: The Case of Harmful Algal Blooms.” *Ecological Economics*, vol. 176 (2020): 106691.

[14]Sergio Alvarez et al., “Valuing Provision Scenarios of Coastal Ecosystem Services: The Case of Boat Ramp Closures Due to Harmful Algae Blooms in Florida,” *Water*, vol. 11, no. 6 (2019): 1250.

[15]Andrew Bechard, “External Costs of Harmful Algal Blooms Using Hedonic Valuation: The Impact of *Karenia brevis* on Southwest Florida,” *Environmental and Sustainability Indicators*, vol. 5 (2020): 100019.

[16]Andrew Bechard, “Gone with the Wind: Declines in Property Values as Harmful Algal Blooms Are Blown Towards the Shore,” *The Journal of Real Estate Finance and Economics*, vol. 62, no. 2 (2021): 242-257.

[17]João-Pedro Ferreira et al., “Impacts of Red Tide in Peer-to-Peer Accommodations: A Multi-Regional Input-Output Model,” *Tourism Economics* (2022).

airborne, causing respiratory symptoms for people working and living along the beach and inland. A 2014 study for six counties in southwest Florida estimated that, if HAB occurrence continued, the annual costs of resulting illnesses for older adults (aged 55 and older) ranged between $60,000 and $700,000, with up to $1 million for severe, long-lasting blooms.[18]

Studies on Freshwater HAB Events Focused on Lake Erie

Our review of freshwater studies found that several of them estimated losses for Lake Erie related to cyanobacterial (or blue-green algae) presence. Consistent monitoring of cyanobacterial HABs through weekly satellite imagery allows researchers to estimate the economic losses resulting from past HABs, as well as those that were predicted, particularly on Lake Erie.[19] One study estimated that a summer-long HAB would result in a reduction of recreational fishing expenditures between $2.2 million and $5.6 million, based on observations from 2011 and 2014 in areas limited to zip codes within 20 kilometers of Lake Erie.[20] A related study predicted that beachgoers and recreational anglers living within 50 miles of Lake Erie would lose $7.7 million and $69.1 million each year, respectively, if water quality conditions were to become so poor that Lake Erie's western basin were closed.[21]

Another study focused on future economic losses because of HABs in the Canadian basin of Lake Erie, including a reduction in the value of waterfront properties, loss of tourism and recreation revenues, an increase in water treatment costs, and a reduction in nonuse values of the lake.[22] The study estimated that the annual economic losses would

[18]Porter Hoagland et al., "The Human Health Effects of Florida Red Tide (FRT) Blooms: An Expanded Analysis," *Environment International*, vol. 68 (2014): 144-153.

[19]National Centers for Coastal Ocean Science, National Oceanic and Atmospheric Administration, "Harmful Algal Blooms Monitoring System," (Silver Spring, MD: no date), accessed March 1, 2022, https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/.

[20]David Wolf, Will Georgic, and H. Allen Klaiber, "Reeling in the Damages: Harmful Algal Blooms' Impact on Lake Erie's Recreational Fishing Industry," *Journal of Environmental Management*, vol. 199 (2017): 148-157.

[21]David Wolf et al., "The Impacts of Harmful Algal Blooms and E. coli on Recreational Behavior in Lake Erie," *Land Economics*, vol. 95, no. 4 (2019): 455-472.

[22]"Nonuse values" refer to values (utilities) derived from the existence of the lake by individuals that do not use the lake directly.

amount to about $272 million in 2015 Canadian dollars over the next 30 years.[23]

A few studies estimated the socioeconomic impacts of HABs that occurred in other freshwater lakes, including reduction in property values, loss of tourism revenues, and a potential increase in health care costs. One study of multiple lakes in six Ohio counties showed that HABs resulted in a decline in home prices from 11 percent to 17 percent for homes near a lake, and 22 percent for homes adjacent to a lake. Using one lake as an example (Grand Lake Saint Marys), that study estimated the onetime capitalization losses for homes near the lake would exceed $51 million. The study noted that this capitalization loss “dwarfs the State of Ohio’s cleanup expenditure of $26 million” for this lake.[24]

Another recent study indicated that higher concentrations of microcystin, a toxin produced by cyanobacteria, were associated with lower birth weights for residents living adjacent to a lake in Michigan. An unexpected reduction in microcystin concentration was found to improve low-birth weights and to avoid $768,500 in average annualized health care costs.[25]

Some Studies Have Examined the Benefits of Responding to HABs

We found that some studies have examined the benefits of responding to HABs, and studies on the costs and benefits of mitigation, control, and prevention actions are emerging. Some studies focused on estimating the benefits of early warnings, forecasts, and nutrient reduction to mitigate and prevent HABs. Forecasts and early warning information were found to mitigate the effects of HABs by allowing people to prepare for and avoid HAB events. For example, annual marine HAB forecasts can allow fishers and shellfishery managers to adjust their harvest timing.

A 2008 study showed that the value of HAB forecasts in the Gulf of Maine over the next 30 years could range from $0.9 million to $51.3 million in 2005 dollars, with the values varying based on HAB frequency and size, prediction accuracy, and the effectiveness of the responses by fishers

[23]Robert B. Smith et al., “Estimating the Economic Costs of Algal Blooms in the Canadian Lake Erie Basin,” *Harmful Algae*, vol. 87 (2019): 101624.

[24]David Wolf and H. Allen Klaiber, “Bloom and Bust: Toxic Algae’s Impact on Nearby Property Values,” *Ecological Economics*, vol. 135 (2017): 209-221.

[25]Benjamin A. Jones, “Infant Health Impacts of Freshwater Algal Blooms: Evidence from an Invasive Species Natural Experiment,” *Journal of Environmental Economics and Management*, vol. 96 (2019): 36-59.

and the public.[26] Another study on Utah Lake (Utah) estimated the value of early warnings to water recreationists of a HAB event in 2017.[27] Specifically, the study estimated approximately $370,000 in improved health because of the use of satellite data for warnings regarding HAB events in the lake (with a sensitivity range of $55,000 to $1,057,000).

A few studies quantified the amount that residents were willing to pay to prevent HABs by reducing nutrients that accumulate and feed algae blooms. However, while these studies used the level of nutrient reduction as the policy objective, they did not estimate the costs to achieve this objective.

For example, one study found that recreational anglers on Lake Erie are willing to pay $8 to $10 more per trip for boating to a fishing site through 1 less mile of HAB-impacted water. For a hypothetical policy that would reduce upstream phosphorus loadings by 40 percent, the same study found that anglers were willing to pay an average of $40 to $60 per trip.[28] Other studies inferred the benefits of prevention using the evaluation of avoided economic damage associated with a reduction in nutrients. For example, one study of Lake Erie showed that the benefits of a policy to reduce fertilizer use would outweigh the costs if they were less than $1.3 billion over 30 years (net present value in 2015 Canadian dollars).[29]

Another study used the potential gains in property values to estimate the benefits of reducing phosphorus in an Ohio watershed. It showed that if phosphorus were reduced between 10 percent and 50 percent in the

[26]Di Jin and Porter Hoagland, "The Value of Harmful Algal Bloom Predictions to the Nearshore Commercial Shellfish Fishery in the Gulf of Maine," *Harmful Algae*, vol. 7, no. 6 (2008): 772-781.

[27]Signe Stroming et al., "Quantifying the Human Health Benefits of Using Satellite Information to Detect Cyanobacterial Harmful Algal Blooms and Manage Recreational Advisories in U.S. Lakes," *GeoHealth*, vol. 4, no. 9 (2020).

[28]Wendong Zhang and Brent Sohngen, "Do U.S. Anglers Care about Harmful Algal Blooms? A Discrete Choice Experiment of Lake Erie Recreational Anglers," *American Journal of Agricultural Economics*, vol. 100, no. 3 (2018): 868-888.

[29]Smith et al., "Estimating the Economic Costs of Algal Blooms in the Canadian Lake Erie Basin."

Upper Big Walnut Creek watershed in Ohio, the increase in property values would range from $1.33 million to $6.66 million in 2010 dollars.[30]

We found one study that compared the costs of alternative control and prevention strategies directly. This study demonstrated the feasibility of using large-scale attached algal growth systems that consume nutrients from the water column and prevent downstream nutrient accumulation and HABs in Lake Erie.[31] It showed that Lake Erie communities would lose $142 million annually, on average, because of HABs that would occur over the next 3 decades, without intervention. The use of the attached algal system would result in net savings, ranging from $29 million to $42 million per year. This would generate higher positive cash flows compared to farm-based best management practices to reduce nutrients loading to Lake Erie.

Areas for Additional Research

Overall, our review identified more studies on (1) marine HABs and freshwater HABs in the Great Lakes than for other freshwater bodies and (2) the immediate economic damages of HABs as compared to those predicting future losses. Meanwhile, research is emerging on freshwater bodies beyond the Great Lakes and the costs and benefits of mitigation, control, and prevention, with increased monitoring of water quality and development of modeling methods.

The studies we reviewed were based on available HAB monitoring data and baseline socioeconomic data for the affected communities. To determine appropriate mitigation, control, and prevention strategies, the associated cost-benefit analysis would require a more extensive body of knowledge, including information on the economic losses associated with the occurrence of HABs and the costs to implement different strategies.

Cost-benefit analysis can help decision makers to develop strategies and plans for the mitigation, control, or prevention of HABs. To support cost-benefit analysis, some studies and an expert panel called for more extensive data gathering on HABs and research on their impacts to help

[30]Hongxing Liu et al., “Valuing Water Quality Change Using a Coupled Economic-hydrological Model,” *Ecological Economics*, vol. 161 (2019): 32-40.

[31]Katherine K. DeRose et al., “Economic Viability of Proactive Harmful Algal Bloom Mitigation through Attached Algal Growth,” *Journal of Great Lakes Research,* vol. 47, no. 4 (2021): 1021-1032.

decision makers respond.[32] The panel made recommendations on a research agenda, including the need to formalize regional and national HAB monitoring, forecasting, and socioeconomic impact assessments to provide a foundation for cost-benefit analysis. Specifically, the panel noted that more information is needed on (1) the economic losses associated with the occurrence of HABs, (2) the costs of implementing alternative strategies and actions and their effectiveness in reducing HABs, and (3) the distribution of the benefits and costs of alternative strategies on different communities and social groups.

[32]See, for example, U.S. National Office for Harmful Algal Blooms, Woods Hole Oceanographic Institution, *Proceedings of the Workshop on the Socio-economic Effects of Marine and Freshwater Harmful Algal Blooms in the United States*.

Appendix IV: Federal Agency Actions to Monitor Ambient Freshwater Harmful Algal Blooms and Hypoxia

Individual federal agencies have taken a range of actions to monitor the risks of harmful algal blooms (HAB) and hypoxia in ambient freshwaters, but these actions are limited in various ways.[1] For example:

Centers for Disease Control and Prevention (CDC). In 2016, CDC launched the One Health Harmful Algal Bloom System, a voluntary reporting system that collects data on HAB events, as well as human and animal illnesses associated with HABs. In most cases, health departments in states and territories report directly in the system, but they can also designate animal health and environmental health partners to report, according to CDC officials. According to a CDC report, 18 states reported HAB events that had occurred between 2016 and 2018.[2] The report stated that the number of reported events or illnesses underrepresents the total that had occurred within and across states.[3]

Environmental Protection Agency (EPA). Since 2015, EPA has collected information monthly on beach closures and advisories in freshwaters caused by HABs, as reported on state websites.[4] However, this effort does not produce a comprehensive list of HAB events, as not all blooms have been reported, and not all lakes are actively monitored, according to EPA. EPA has also collaborated with local volunteers to track HABs in some states.[5] In addition, EPA hosts the Water Quality Portal, which the agency describes as the nation's largest source for

[1]"Ambient" refers to open waters such as rivers, lakes, and streams, as opposed to closed water supply systems that distribute treated water or wastewater.

[2]Virginia A. Roberts et al., "Surveillance for Harmful Algal Bloom Events and Associated Human and Animal Illnesses — One Health Harmful Algal Bloom System, United States, 2016–2018," *Morbidity and Mortality Weekly Report*, vol. 69, no. 50 (Centers for Disease Control and Prevention, 2020).

[3]For more information on data collected through CDC's One Health Harmful Algal Bloom System, see https://www.cdc.gov/habs/data/.

[4]In 2021, EPA released a story map, which compiles state-issued recreational water body and drinking water health advisories because of freshwater HABs from across the country. To access EPA's story map, see https://storymaps.arcgis.com/stories/d4a87e6cdfd44d6ea7b97477969cb1dd.

[5]According to EPA officials, EPA's Region 1 Office and the University of New Hampshire have collaborated with local groups to develop a program for tracking and monitoring HABs. It includes crowdsourcing reports of blooms using the bloomWatch smartphone application, which allows users to document blooms on a public website. For more information, see https://cyanos.org/.

water quality monitoring data.[6] Though not specific to HABs, these data may help EPA advance monitoring for HABs. For example, in its fiscal year 2019 update, EPA reported that it was using data from the Water Quality Portal to help validate the Cyanobacteria Assessment Network's satellite algorithms.

National Park Service. The National Park Service monitors water bodies for HABs in some of its parks, but efforts vary by park and region. According to agency officials, monitoring in parks is often conducted in coordination with other federal and state agencies, as well as universities.

U.S. Army Corps of Engineers. In addition to monitoring some of the water bodies it manages for HABs, the Corps also plays a role in developing monitoring technologies to help detect HABs, according to Corps officials. For example, the agency's Engineer Research and Development Center is working with state and federal agencies, as well as universities, to develop technologies, such as sensors, that can detect HABs in freshwater systems. In addition, the Corps researches uses of remote sensing software tools for estimating HAB water quality indicators at inland lakes and reservoirs that the agency manages.

U.S. Fish and Wildlife Service. The Fish and Wildlife Service's Wildlife Health Office works with National Wildlife Refuges across the country to identify and minimize wildlife morbidity and mortality from HABs at those particular sites. For example, the agency's veterinarians assist refuges with monitoring and recognizing HAB events.

U.S. Geological Survey (USGS). USGS has hundreds of real-time water quality monitoring sites throughout the nation that take physical, chemical, and biological measurements, some of which officials said have shown promise as indicators for potential non-toxic HAB or hypoxia events. USGS is currently funding projects to advance real-time monitoring, remote sensing, and use of molecular techniques to identify and predict the occurrence of HABs and the toxins they produce, according to the agency's website.[7] USGS is also developing a Next Generation Water Observing System to advance emerging monitoring technologies,

[6]The Water Quality Portal contains over 380 million water quality data records from 900 federal, state, tribal, and other partners. For more information, see https://www.epa.gov/waterdata/water-quality-data.

[7]U.S. Geological Survey, "Harmful Algal Bloom (HAB) Cooperative Matching Funds Projects," accessed May 19, 2022, https://www.usgs.gov/mission-areas/water-resources/science/harmful-algal-bloom-hab-cooperative-matching-funds-projects.

including those related to HABs and hypoxia, according to agency officials.

Appendix V: Summary of Selected Localities and Tribes' Experiences in Managing the Risks of Harmful Algal Blooms and Hypoxia

We interviewed officials from selected localities and tribes to learn about their experiences in managing the risks of harmful algal blooms (HAB) and hypoxia, including the challenges they face and their interactions with federal agencies in this effort. This appendix presents a summary of these entities' experiences based on the information we gathered from these interviews.

Experiences of Selected Local Officials

Local government officials are often the first to respond to HAB events, and local governments may interact with both state and federal agencies to manage the risks of HABs and hypoxia. We interviewed officials from four local governments from the four Census regions to obtain perspectives on how local government officials respond to HABs and hypoxia.

Florida. We interviewed an official from a county in Florida that has experience with marine HABs and hypoxia, particularly red tide events, as well as freshwater HAB and hypoxia events. Officials in this county work with both state and federal agencies to track red tide events. These red tide events have had health and environmental effects. In this county, red tide events have been linked to respiratory issues, especially in people with preexisting respiratory conditions. The official said that these events can cause declines in tourism and recreation. The official also stated that the county had implemented various efforts to prevent HABs and hypoxia, including stormwater retention, natural conservation, and street sweeping, all in an effort to remove nutrients.

Iowa. Officials from a city in Iowa told us that while HABs are of concern to city leadership, the city's primary concern is reducing nutrient runoff from agricultural production that could contribute to hypoxia in the Gulf of Mexico. Officials from the city told us that HABs do not directly impact the city's drinking water supply; however, nitrogen runoff can negatively affect the water supply. In working toward its nutrient reduction goal, the city used federal funding to assist private landowners in implementing practices in their fields to reduce nitrogen and phosphorus runoff. City officials told us that the nutrient reduction efforts work toward improving water quality by reducing nitrogen runoff. Overall, the city faces challenges with the scale on which nutrient reduction must take place in order to have a meaningful effect on the Gulf of Mexico hypoxia zone.

Oregon. An official from a city in Oregon told us that the city had significant experience with the effects of HAB toxins in the local water supply. This city experienced a HAB event in 2018 that necessitated the issuance of a drinking water advisory for vulnerable populations. The city's experience with this bloom led the city's management to allocate specific staff to monitor the local watershed for algae. As a result of the city's experience with HABs in 2018, the city government has invested in machines that allow technicians to perform in-house testing on water samples.

Vermont. Officials we spoke to from a town in Vermont said that HAB events impact the town's recreational lake, including a large HAB in 2017. This HAB event caused fish deaths and prevented the public from using the local lake for recreation. To counter the risks posed by future blooms on the lake, a committee of local stakeholders obtained state and federal funding to install a system to aerate the lake.

Experiences Shared by Selected Tribal Officials

Members of tribal nations use the waters on their lands in culturally specific ways and, therefore, can experience unique effects from HABs and hypoxia. Tribal water uses can be repetitive and long term, according to tribal documentation. In addition, exposures to HABs can occur second-hand through the use and trade of plants and animals that have been in contact with HABs. Tribal cultural uses of waters include

- collection and consumption of aquatic plants;
- collection and consumption of aquatic animals;
- spiritual activities;
- immersion in waters for ceremonies;
- celebrations, such as water festivals or activities; and
- education of youth in tribal ways and roles.

We interviewed officials from four tribal nations, one in each of the Census Bureau's regions, who told us about how HABs and hypoxia uniquely impact their communities. Although the tribes had varying levels of experience with exposure to HAB events, officials from all four tribes we interviewed told us that their tribes perform some monitoring of HABs or hypoxia.

An official from a tribe in the West described the tribe's experiences with both freshwater and marine HABs. The freshwater HABs in this tribal nation occur on a river that serves as a source of subsistence fishing and a site for ceremonial use for the community. A tribal official from this nation told us that the community has a unique relationship with the river, and the tribe believes that the ceremonies performed in the water are a religious duty. The type of fishing that the tribe performs in the river involves exposure to the whole upper body of the person fishing, exposing that person to a risk of symptoms, such as rashes, sores, dizziness, and nausea, related to exposure to HAB toxins. However, because these fishing practices serve as a source of subsistence for the community, the community continues to fish, despite the risks.

Marine HABs also impact a food source for the same tribal community. Because marine HABs that impact mussels and various shellfish affect both tribal and state resources, the tribe works with the state government on testing water samples. An official from this tribe described this collaboration with the state government as critical to addressing the monitoring and testing resource issues that can impede the tribe's response to HAB events. The official also said that the Environmental Protection Agency (EPA) assists the tribe in processing water samples and providing funding used to pay the staff collecting those samples. The official said that the costs of laboratory testing would be prohibitively expensive without the use of outside research grants and EPA labs.

An official from a tribe in the Midwest said that the tribe uses federal funding and works with the state to maintain a program for HABs observation and testing, including using an EPA-certified lab to test water quality. The official from this tribe also described cultural impacts of HABs on the community. Pollutants, including those produced by HABs, affect the community's traditional way of living because the people cannot consume locally caught fish. Algal growth can also affect the growth of wild rice, an important cultural resource for this community.

Appendix VI: Additional Examples of Federal Funding and Research to Help States, Localities, and Tribes Respond to Harmful Algal Bloom and Hypoxia Events

As discussed previously, federal agencies help state, local, and tribal governments respond to harmful algal bloom (HAB) and hypoxia events by providing funding and conducting research. This appendix provides additional examples of actions that federal agencies have taken in each of these areas.

Funding

Additional examples of federal agency funding efforts include:

Environmental Protection Agency (EPA). EPA provides funding to states and tribes for HAB-related efforts through existing funding mechanisms, such as Clean Water Act grants.[1] Officials from eight states in our discussion group sessions told us that their states used Clean Water Act Water Pollution Control Grant funding to train staff or to purchase equipment to identify HAB toxins.[2] In addition, EPA provides funding to public water systems to finance infrastructure improvements through the Safe Drinking Water Act. Such infrastructure improvements could include better water treatment systems to address HABs in drinking water systems.

National Oceanic and Atmospheric Administration (NOAA). NOAA's U.S. Integrated Ocean Observing System Office provides funds to support the National Harmful Algal Bloom Observing Network's activities related to the detection, forecasting, and monitoring of HABs on a regional scale, in partnership with local communities and research institutions. In addition to the Ecology and Oceanography of HABs program discussed previously, NOAA provides funding for HABs-related research and technology development through two other programs authorized under the act. First, the Monitoring and Event Response for HABs program funds projects to build capacity along the coasts for enhanced HAB monitoring and response. Second, the Prevention, Control, and Mitigation of HABs program funds research to develop, demonstrate, and apply technologies for preventing, controlling, or mitigating HABs. This program also funds socioeconomic research to

[1]EPA also develops outreach materials for states and tribes to provide guidance about EPA funding sources that can be used to help manage HABs and their toxins. These materials include fact sheets describing possible funding sources for managing cyanobacterial HABs and cyanotoxins in drinking water and protecting source waters (such as rivers, streams, lakes, reservoirs, springs, and groundwater) of public drinking water supplies and private wells.

[2]EPA awards Water Pollution Control Grants under section 106 of the Clean Water Act to states (including territories and the District of Columbia), interstate agencies, and eligible tribes to establish and implement water pollution control programs. *See* 33 U.S.C. § 1256.

assess the impacts of HAB events on coastal economies, and the costs and benefits of mitigation strategies to aid managers in devising cost-effective management strategies.

Natural Resources Conservation Service (NRCS). NRCS provides financial assistance to individual ranchers, farmers, and landowners through programs such as the Environmental Quality Incentives Program. The program provides funds to implement conservation practices and activities on agricultural lands, such as establishing riparian buffers, to reduce nutrient and sediment runoff, which can help prevent HABs and hypoxia. Riparian buffers use vegetation, such as grass or shrubs planted along waterways, to filter and absorb nutrients and other materials in runoff. NRCS has other programs that provide similar funding and benefits, including the Conservation Stewardship Program and the Regional Conservation Partnership Program.

Regional interagency efforts. EPA and NRCS, along with other federal agencies, participate in regional interagency efforts, such as the Mississippi River/Gulf of Mexico Hypoxia Task Force and the Interagency Task Force for the Great Lakes Restoration Initiative. Through these efforts, the agencies make funding available to states, tribes, localities, and other entities to improve water quality in the Mississippi River Basin, the Gulf of Mexico, and the Great Lakes, which can help to reduce HABs and hypoxia.

Research

Additional examples of federal agency research efforts include:

EPA. EPA officials stated that the agency’s Office of Research and Development is conducting studies on various HABs-related topics, including HAB monitoring and assessment; preventing, treating, and managing HABs and their impacts in water bodies, ambient water, and drinking water; and human and environmental adverse health outcomes from exposure to HABs and associated toxins.

National Institute of Food and Agriculture. This U.S. Department of Agriculture agency has several programs that support research related to HABs and hypoxia, according to agency officials. For example, the Institute's Agriculture and Food Research Initiative awards competitive grants for research on working agricultural lands, such as research related to nutrient and sediment runoff into waterways in the Lake Erie basin.

National Science Foundation. According to agency officials, the National Science Foundation plays an important role in supporting HAB-related research by, for example, funding research to improve HAB toxin sensors and to better understand the direct and indirect causes and ecological consequences of HABs in coastal regions. In addition, the agency has worked with the National Institute of Environmental Health Sciences to jointly fund interdisciplinary research on marine-related health issues, such as the health effects of eating seafood containing toxins produced by HABs.

NOAA. In addition to its HAB-related research programs discussed previously, NOAA officials told us that the agency is also conducting research to increase technology options for controlling HABs in marine and coastal waters. For example, the officials described a research project that involved nanotechnology (i.e., nanobubble ozone technology) to eliminate blooms and toxins in waters.[3]

U.S. Geological Survey (USGS). According to agency officials, USGS has an algal toxin laboratory and associated science team that conduct research on the occurrence of algal toxins in the nation's waters, toxin exposures to humans and wildlife, and the factors that contribute to the production and release of algal toxins to water bodies.[4] The team's research activities focus on identifying and understanding environmental drivers of algal toxin production and release, determining the most significant exposure routes to humans and wildlife, and developing diagnostic tools to understand if there are health impacts of algal toxins on wildlife in freshwater environments.

Working group support for the National HAB Committee.[5] The working group has supported the National HAB Committee's effort to

[3]According to NOAA officials, this project was developed using a Cooperative Research and Development Agreement, which is a type of written agreement between a private U.S. company, university, or other entity, and a NOAA Laboratory or Science Center to work together on a collaborative research and development project. NOAA also works with tribes and underserved communities through such agreements, according to NOAA officials.

[4]For more information on the science team, see https://www.usgs.gov/programs/environmental-health-program/science/toxins-and-harmful-algal-blooms-science-team.

[5]The National HAB Committee is a group of academic, state, and federal agency experts interested in national HAB issues.

update its 2005 Harmful Algal Research and Response National Environmental Science Strategy report in various ways.[6] For example, according to working group documentation, representatives from several working group agencies serve as ex-officio members on the committee and the working group has provided technical assistance to help the committee update the report.

[6]The working group has described this 2005 report as an action plan that gave recommendations on research and other topics for the U.S. HAB community. For more information, see John S. Ramsdell, Donald M. Anderson, and Patricia M. Glibert (Eds.), *Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015* (Washington, D.C.: Ecological Society of America, 2005).

Appendix VII: Comments from the Department of Commerce

UNITED STATES DEPARTMENT OF COMMERCE
Office of the Chief Financial Officer and
Assistant Secretary for Administration
Washington, D.C. 20230

May 6, 2022

Mr. Jose Alfredo Gomez
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Gomez:

Thank you for the opportunity to review and comment on the Government Accountability Office's (GAO) draft report entitled *Water Quality: Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia* (GAO-22-104449).

The Department of Commerce agrees with GAO's four recommendations directed to the National Oceanic and Atmospheric Administration and Environmental Protection Agency Administrators who are the co-chairs of the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act. Enclosed is our response to the draft report.

Should you have any questions, please contact MaryAnn Mausser, GAO Liaison, at (202) 482-8120 or MMausser@doc.gov.

JENNIFER LANE
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Date: 2022.05.02 17:51:59 -04'00'

Jennifer S. Lane

Senior Advisor to the Deputy Secretary
Performing the non-exclusive duties of the Chief Financial Officer and Assistant Secretary for Administration

Enclosure

Department of Commerce
National Oceanic and Atmospheric Administration
Response to the GAO Draft Report Entitled
Water Quality: Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia
(GAO-22-104449, May 2022)

General Comments

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) appreciates the opportunity to review the Government Accountability Office's (GAO) report on Federal agencies' harmful algal bloom (HAB) and hypoxia efforts. NOAA agrees with the majority of the well-informed and thorough content in the report, and with all of GAO's recommendations. However, NOAA would encourage GAO to provide additional background information in the report, particularly with regard to the activities undertaken by the Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act (IWG-HABHRCA or "working group").

GAO refers to the IWG-HABHRCA 2016 national Research Plan and Action Strategy (RPAS), but it is important to note that this working group has also produced several other significant reports, including the 2016 RPAS and a subsequent one for the Great Lakes region ("Harmful Algal Blooms and Hypoxia in the Great Lakes Research Plan and Action Strategy: An Interagency Report"). These have been followed by regular progress reports, a 2021 "Planning Document for Coordination," and multiple workshops, coordinated efforts, and stakeholder engagements. NOAA would encourage GAO to reference the working group's published reports, materials, and activities beyond the RPAS throughout the document. Acknowledging these reports will provide greater context for the accomplishments and priorities of the working group. The current coordination role of the working group has allowed for enhanced Federal HAB and hypoxia efforts, coordinated funding approaches, the development of interagency priorities, and regular convening of multiple fora to advance coordinated prevention, mitigation, control, and response to HAB events.

NOAA would further recommend that the report reference the numerous differing mandates and authorities among member agencies and the currently ascribed coordination framework designated to the working group by the White House Subcommittee on Ocean Science and Technology (SOST) or the National Science and Technology Council (NSTC). NOAA believes that additional reference to these coordinated efforts, designated responsibilities, activities, and deliverables will provide a fuller context to the report's findings.

NOAA Response to GAO Recommendations

Recommendation 1: "The Administrator of NOAA and the Administrator of the EPA, in collaboration with the members of the working group, should document and define what a national HAB and hypoxia program would entail, including identifying the program's resource needs."

NOAA Response: NOAA agrees with this recommendation and sees value in documenting and defining what a national HAB and hypoxia program would entail, including identification of the program's resource needs to assist with its execution. However, we are concerned that neither NOAA nor EPA have specific authorities in HABHRCA to oversee activities carried out by the other 18 member agencies of the working group, nor are these expectations or abilities that have been given to the working group by the White House SOST or NSTC under the current coordination framework and interpretation of responsibilities designated to the working group in HABHRCA. As communicated previously, the working group has functioned as a coordination entity to account for the varying mandates, authorities, and resources associated with its 20 member agencies. NOAA will work with EPA, via the working group, to define its resource needs, and build on the information included in the working group's recent coordinated planning document, to realize a more defined national program in accordance with GAO's recommendations.

Recommendation 2: "The Administrator of NOAA and the Administrator of the EPA, in collaboration with the members of the working group, should develop performance measures to assess the working group's efforts, including the extent to which the recommended goals from the Research Plan and Action Strategy have been achieved."

NOAA Response: NOAA agrees with this recommendation and sees value in developing performance measures to assess the working group's efforts and the extent to which the recommended goals from the Research Plan and Action Strategy (RPAS) have been achieved. Currently, performance measures for evaluating progress for HAB and hypoxia-related efforts have already been developed at the agency-specific level, given the varying authorities, resources, and responsibilities of individual agencies for addressing HABs and hypoxia. As correctly noted by GAO, they have also been generally accounted for and will continue to be monitored, as milestones and deliverables in various progress reports. Moving forward, NOAA will build upon these efforts and work with EPA, in collaboration with working group members, to develop formal performance measures.

Recommendation 5: "The Administrator of NOAA and the Administrator of the EPA, in collaboration with the members of the working group, should develop a national goal for the group focused on efforts to prevent HABs and hypoxia."

NOAA Response: NOAA agrees with this recommendation. NOAA will work with EPA and the working group to develop a national goal focused on prevention. To date, the working group has coordinated goals, objectives, and milestones for the individual agencies in the working group through the SOST-requested Planning Document for Coordination and the RPAS. Prevention efforts have been a specific focus of those documents in past years and have been nationally coordinated rather than aligning all agencies to a central goal.

Recommendation 6: "The Administrator of NOAA and the Administrator of the EPA, in collaboration with the members of the working group, should coordinate the development of a more comprehensive body of information on the costs and benefits of mitigation, control, and prevention actions for use by state, local, and tribal governments."

NOAA Response: NOAA agrees with this recommendation. This action would build on current efforts undertaken by NOAA and other members of the working group to regularly engage with state, local, and tribal governments in workshops, webinars, available resources, trainings, and other venues and regularly offer expertise, support, and assistance, including providing extramural funds to assist with developing prevention, control, and mitigation strategies.

Appendix VIII: Comments from the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF WATER

Mr. Alfredo Gomez
Director
Natural Resources and Environment
U.S. Government Accountability Office
Washington, D.C. 20548

Dear Mr. Gomez:

Thank you for the opportunity to review and comment on the U.S. Government Accountability Office's (GAO) draft report, "Water Quality Agencies Should Take More Actions to Manage Risks from Harmful Algal Blooms and Hypoxia," Report #GAO-22-104449. The purpose of this letter is to provide the U.S. Environmental Protection Agency's (EPA) response to the draft report findings, conclusions, and recommendations. EPA generally agrees with the GAO's findings, conclusions, and recommendations and is providing additional clarifications to the recommendations in this response. However, EPA noted an important technical oversight related to freshwater harmful algal/cyanobacterial blooms (HABs, HCBs) monitoring and is providing information for GAO to consider including in the final report.

GAO issued in the draft report six (6) recommendations: two (2) to the EPA and four (4) to the National Oceanic and Atmospheric Administration (NOAA) and EPA as the co-chairs of the Interagency Working Group (IWG) on the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA). EPA's responses to GAO's recommendations are provided below.

Recommendation 1: *The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should document and define what a national HAB and hypoxia program would entail, including identifying the program's resource needs.*

EPA Response: EPA agrees with this recommendation that as co-chairs of the IWG, EPA and NOAA should coordinate with the IWG to define what a national HABs and hypoxia program would entail and identify the resources needed to implement the program. As previously stated in the draft report, EPA and NOAA have limited oversight authority over IWG member agencies and no direct appropriations or additional authorities are given to the IWG or its co-chairs. Since each agency has their own competing authorities and mandates, as well as funding obligations and priorities, EPA and NOAA intend to collectively define the scope of the national program and identify available resources to implement the program in consultation with the IWG member agencies.

Recommendation 2: *The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should develop performance measures to assess the working group's* *efforts, including the extent to which the recommended goals from the Research Plan and Action Strategy have been achieved.*

EPA Response: EPA agrees with the recommendation that as co-chairs, EPA and NOAA should coordinate with the IWG to develop performance measures to assess the working group's efforts, including the extent to which the recommended goals from the Research Plan and Action Strategy have been achieved since its initiation in 2016.

Recommendation 3: *The Administrator of EPA, working with the other members of the working group, should develop an interagency framework, including prioritizing water bodies and identifying resource needs, to expand monitoring of freshwater HABs and hypoxia.*

EPA Response: EPA agrees with this recommendation. In consultation with other IWG member agencies, EPA intends to coordinate the development of a framework and determine the resources needed to prioritize water bodies based on magnitude, spatial extent and frequency and expand monitoring for HABs and hypoxia in freshwater systems. As described in this GAO report and its appendices, there are multiple federal monitoring efforts for freshwater focused on addressing different decision needs at different spatial and temporal scales. EPA partners with states and tribes on the National Aquatic Resource Surveys (NARS) which include indicators of the potential for HABs. While not providing comprehensive assessments of individual waters, these statistically representative surveys report on the extent of waters at national and regional scales with microcystin detections. Supplemental analysis of the nationally consistent NARS datasets has provided valuable insights for prioritization and protection activities. EPA also works with states, tribes, and other organizations on local water quality monitoring, assessment and prioritization of protection, and restoration actions. Many of these agencies and organizations already share data through the water quality portal, along with federal agencies. More recently, EPA launched a smartphone app called bloomWatch that leverages the power of volunteers through crowd sourcing. Users take and submit photos reporting potential HABs. EPA is developing a proof of concept for a centralized and standardized reporting and information exchange approach that leverages the Water Quality Portal, bloomWatch, and other existing tools to track local, regional, and national level HAB/HCB related events.

Recommendation 4: *The Administrator of EPA, working with the other members of the working group, should develop an interagency framework, including prioritizing water bodies and identifying resource needs, to expand forecasting of freshwater HABs and hypoxia.*

EPA Response: EPA agrees with this recommendation. In consultation with other IWG member agencies, EPA intendsto coordinate to develop an interagency framework, including prioritizing water bodies based on magnitude, spatial extent, and frequency, and identify resource needs, to expand forecasting of freshwater HABs and hypoxia.

Recommendation 5: *The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should develop a national goal for the group focused on efforts to prevent HABs and hypoxia.*

EPA Response: EPA agrees with this recommendation that, in consultation with NOAA and the other IWG member agencies, it should identify a national goal on efforts to prevent HABs and hypoxia. The IWG will build upon existing prevention efforts included in several sections and Appendix 4 in the "2016 Research Plan and Action Strategy," the "2017 Great Lakes Research Plan and Action Strategy,"

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and the EPA's Great Lakes Research Initiative (GLRI) and the 2016 Nutrient Annex 4 Objectives and Targets Development Task Team Multi Modeling Report (Annex 4).

Recommendation 6: *The Administrator of NOAA and the Administrator of EPA, in collaboration with the members of the working group, should coordinate the development of a more comprehensive body of information on the costs and benefits of mitigation, control, and prevention actions for use by state, local, and tribal governments.*

EPA Response: EPA agrees that, in coordination with NOAA and the IWG member agencies, it intends to work to determine the costs and benefits of mitigation, control, and prevention actions. EPA understands that this exercise will require the identification of the resources, time, and information needed to adequately develop a comprehensive cost-benefit analysis because of the large number of existing strategies for the mitigation, control and prevention of HABs. The IWG does not have the funding to estimate these direct, indirect, or intangible costs and benefits for each of these existing strategies. Therefore, the IWG will need additional resources from Congress to build upon existing work and coordinate with other agencies or outside groups to get the expertise needed to further develop these assessments. For example, in 2019 the Global Ecology and Oceanography of Harmful Algal Blooms research programme (GlobalHAB), with contributions from academics from various universities and regions, developed the report, *Solutions for managing cyanobacterial blooms: A scientific summary for policy makers* to provide an overview of the products and physical, chemical and biological solutions available for control of cyanoHABs in lakes, and some detail on their benefits and relative costs. In addition, in 2021, the Interstate Technology and Regulatory Council (ITRC) published in a guidance document a list of in-lake strategies for the prevention, control and mitigation of freshwater HABs. This list includes information on effectiveness, advantages, limitations, relative cost, and regulatory and policy considerations.

EPA is grateful to the GAO for its recommendations. Again, we generally agree with them and have provided additional clarifications and noted where lack of resources or authority will limit the agency's ability to fulfill them. Should you have any further questions, feel free to contact me or have your staff contact Elizabeth Behl at Behl.Betsy@epa.gov or 202-566-0788.

Sincerely,

BENITA BEST-WONG Digitally signed by BENITA BEST-WONG Date: 2022.05.03 15:51:39 -04'00'

Benita Best-Wong
Deputy Assistant Administrator

Attachment:
1. Technical Comments

cc: Macara Lousberg, OW/IO
Tiffany Crawford, OW/IO

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Deborah Nagle, OW/OST
Betsy Behl, OW/OST
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Appendix IX: GAO Contact and Staff Acknowledgments

GAO Contact

J. Alfredo Gómez, (202) 512-3841 or gomezj@gao.gov

Staff Acknowledgments

In addition to the contact named above, Susan Iott (Assistant Director), Emily Ryan (Analyst-in-Charge), Joshua Wiener (Analyst-in-Charge), Bruna Oliveira, and Samantha Piercy made key contributions to this report. Also contributing to the report were Josephine Ballenger, Xiang Bi, Virginia Chanley, William R. Chatlos, Carole Cimitile, Philip Farah, Ellen Fried, Karen Howard, Benjamin T. Licht, Donna Morgan, Patricia Moye, Diane Raynes, William Reinsberg, Sara Sullivan, and Sarah Veale.

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